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REMEDIAL INVESTIGATION FINAL REPORT
APPENDIX B, PART 1

Report

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GROUND WATER AND TAILINGS INVESTIGATION

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SILVER BOW CREEK REMEDIAL INVESTIGATION
DRAFT FINAL REPORT

GROUND WATER AND POINT SOURCE INVESTIGATION
Part 1: REPORT

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PREFACE

Silver Bow Creek originates north of Butte, Montana and is a major tributary to the upper Clark Fork River. Mill tailings and other mining wastes in and near the creek contribute to substantial downstream contamination, particularly by potentially toxic elements: arsenic, cadmium, copper, lead, iron, and zinc. These elements and others were present in the mine ore and remain as by-products of the milling and smelting processes.

The history of mining in the Butte area began with the discovery of placer gold in Silver Bow Creek, in late summer of 1864. Several townsites and camps sprung up among the diggings. However, these operations were short-lived, and most of the miners left by 1869. Those who stayed began prospecting the quartz lode deposits of silver and the associated complex copper ores on the Butte Hill. Their efforts culminated in a silver rush, which began in the mid-1870's and revived the old camp. During that time world-class deposits of copper ore were identified. By 1881, Butte had become one of the nation's major mining centers; the district attained national dominance in copper mining by the mid-1890's and international prominence by the turn of the century. By 1915, Anaconda Copper Mining Company led the industry; but in 1980, in response to a depressed copper market, Anaconda closed all the underground mines and continued active mining only in the Berkeley Pit (established in 1955). In 1977, Anaconda became a subsidiary of Atlantic Richfield Company (ARCO). ARCO closed the Berkeley Pit in 1982 and the East Berkeley pit in 1983.

In addition to mining, various ore processing facilities also operated in the Butte area. The first two mills were erected in 1874 to smelt gold and silver. Ten years later, Marcus Daly, one of the founders of the Anaconda Company, built a copper smelter 27 miles west of Butte and planned the city of Anaconda. The Anaconda Smelter was moved to a new location in the city in 1900, and operated from 1903 to 1980.

The history of over 100 years of continuous mining and related activities changed the area's natural environment greatly. Early mining, milling, and smelting wastes were dumped directly into Silver Bow Creek and transported downstream to the Clark Fork River. In 1911, the first treatment pond was built by Anaconda Company near Warm Springs, Montana, to settle out wastes from Silver Bow Creek before the water was allowed to move on. In 1916 and 1959, two more treatment ponds began operation. Silver Bow Creek continued to receive raw mining and milling wastes until 1972, when a treatment plant was added to the Weed Concentrator in Butte. Creek contamination problems were compounded by urban and domestic sewage, wood products treatment plants, phosphate and manganese production facilities, and chemical factories.

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In 1983, the U.S. Environmental Protection Agency (USEPA) designated Silver Bow Creek, contiguous portions of the upper Clark Fork River, and their environs as a high priority Superfund clean-up site. The site extends from Butte to Deer Lodge, Montana, generally following the course of Silver Bow Creek and the upper Clark Fork River. Because the various mining activities interrupted the natural flow of Silver Bow Creek, the beginning of the creek for this investigation was established as the confluence of the Metro Storm Drain and Blacktail Creek, within the city limits of Butte. The site begins at the start of the Metro Storm Drain and ends at the Kohrs Bridge north of Deer Lodge.

The Silver Bow Creek Remedial Investigation (SBC RI) project consisted of coordinated individual studies to develop data on the extent and severity of contamination within the site. Results of the studies are reported in several volumes. A Summary Final Report discusses the entire project; final reports for each individual study have been issued as appendices to the Summary, as shown below:

- Surface Water and Point Source Investigation, Appendix A, Parts 1 and 2;
- Ground Water and Tailings Investigation, Appendix B, Parts 1-4;
- Warm Springs Ponds Investigation, Appendix C, Parts 1 and 2;
- Algae Investigation, Appendix D, Part 1;
- Vegetation Mapping, Appendix D, Part 2;
- Agriculture Investigation, Appendix D, Part 3;
- Macroinvertebrate Investigation, Appendix E, Part 1;
- Bioassay Investigation, Appendix E, Part 2;
- Fish Tissue Investigation, Appendix E, Part 3;
- Waterfowl Investigation, Appendix E, Part 4; and
- Laboratory Quality Assurance/Quality Control Program, Appendix F.

The Solid and Hazardous Waste Bureau (SHWB) of the Montana Department of Health and Environmental Sciences (MDHES) administered the USEPA appropriations to conduct this project. The Montana SHWB program manager was Mr. Michael Rubich. MDHES contracted with Multi-Tech in October 1984 to perform the SBC RI under contract No. 50341-1202503. The Project Manager at MultiTech was Mr. Gordon Huddleston.

MultiTech was assisted in the SBC RI work by Stiller and Associates of Helena and various other subcontractors. Several state and federal agencies also provided technical information and expertise, including the USEPA bioassay team, the Montana Department of Fish, Wildlife and Parks, the Montana Water Quality Bureau, and the USEPA Montana Field Office.

Information developed in the SBC RI will be used in the next phase of the project, the Feasibility Study, to evaluate options for site remediation.

EXECUTIVE SUMMARY

The Ground Water and Tailings Investigation of the Silver Bow Creek Remedial Investigation was conducted to evaluate the extent and severity of ground water contamination to Silver Bow Creek, to evaluate the significance of tailings deposits as contaminant sources, and to develop other information useful in evaluating remedial alternatives for this CERCLA site. Data collected between December 1984 and January 1986 provided the basis for determining contaminant sources, identifying contaminant transport mechanisms, and evaluating the impacts of contaminated ground water and tailings deposits on Silver Bow Creek. The RI focused on six contaminants: arsenic, cadmium, copper, iron, lead and zinc.

Definite evidence of severe and extensive ground-water contamination was found, primarily in the Butte Metro Storm Drain (MSD) area and upper Silver Bow Creek. Both the upper MSD (Parrot) buried tailings and Colorado Tailings are significant sources of contaminants with markedly elevated metals levels. The buried tailings from the Butte Reduction Works (BRW) also appears to be a major source of contamination. BRW tailings metals concentrations were not directly measured but ground water beneath these tailings is severely degraded and contributes significant metals loads to Silver Bow Creek. This degraded ground water poses potential hazards to human health; however, only a few domestic wells are located near the degraded zones. Federal drinking water standards generally were not exceeded in domestic wells sampled, although several domestic wells did have measurable arsenic concentrations approaching the primary drinking water standard.

Ground water beneath streamside tailings deposits in areas downstream from Rocker was not found to be contaminated during the RI period, with one exception. The upper portion of the alluvial aquifer underlying the Ramsay Flats tailings was slightly degraded in comparison with deeper portions of the aquifer. Given that precipitation was below normal, the impacts of overlying tailings on shallow ground water are probably more significant than indicated during this RI period. Surface soils around the site of the old Anaconda timber treatment plant near Rocker have elevated levels of arsenic. However, no measurable impacts to Silver Bow Creek water quality were observed in this area during the RI, and ground water at the plant site has not been characterized.

Four principal mechanisms for mobilizing contaminants from tailings into surface and ground water in the RI study area were identified:

(1) Direct infiltration of contaminants into underlying soils and groundwater.

(2) Ground-water flux through tailings deposits.

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(3) Capillary action driving metallic salts to the surface with subsequent entrainment by surface runoff.

(4) Direct erosion and entrainment of streamside tailings.

Infiltration studies on exposed tailings showed total, water soluble, and acid extractable metals were greatly elevated in comparison with background levels in natural soils. Analysis of soil beneath tailings indicates that contaminants have moved out of the tailings from five inches (lead) to over twenty inches (cadmium and arsenic). The apparent order of decreasing contaminant mobility is arsenic > cadmium > zinc > copper > lead.

Only a limited amount of water movement from surface tailings into ground water occured during RI period. However, preliminary computer modelling indicates that water flux would be substantial during normal or above normal precipitation periods. Although ground-water flux through buried tailings was not directly measured, the data collected clearly indicate that subsurface tailings are releasing contaminants to ground water.

Accumulation of metal-rich, complex mixed-sulfate salts and hydrated oxide salts on tailings surfaces provide the potential for contaminant movement during periods of precipitation sufficient to cause surface runnoff from such areas. Previously deposited channel bank sediments are a potential source of contaminants, but stream flows were not high enough to cause significant stream bank tailings erosion during this RI.

Ground-water inflows are significant sources of contaminant loads to Silver Bow Creek and are discussed in Appendix A, Surface Water and Point Source Investigation. Ground water inflow to the Butte MSD area is a major contributor to the zinc, cadmium, and sulfate loads in Silver Bow Creek. Ground water entering the creek between Montana Street and the Colorado Tailings is a major source of copper, zinc, arsenic, cadmium, and sulfate.

Principal recommendations for additional ground-water and tailings studies which may be necessary for completion of the RI process are as follows:

(1) Further delineation of the source(s) and extent of ground-water contamination in both the upper MSD and the Butte Reduction Works vicinity.

(2) An analysis of available historic water quality data from process ponds on the Weed Concentrator Complex and associated discharges to the metro storm drain.

(3) Further characterization of the vadose zone during periods of average and above-average precipitation to more completely evaluate the impacts of surface tailings on ground and surface water.

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1.0 INTRODUCTION

The objective of the Silver Bow Creek Remedial Invesigation (SBC RI) is to determine the extent and severity of contamination within the Silver Bow Creek/Upper Clark Fork River System (Map 1-1). Once the extent and severity of contamination within the site has been determined, the risk to humans can be assessed, and feasibility studies to develop remedial actions can be completed.

The SBC RI Ground Water and Tailings Investigation was designed and implemented to develop new data that could be used in conjunction with existing data, (1) to describe the extent and severity of ground-water and tailings contamination in the Silver Bow Creek and upper Clark Fork River basins and (2) to assist in the evaluation, selection, and design of remedial alternatives. This report is the result of the investigation.

The Silver Bow Creek system has been contaminated by over 100 years of mining and smelting activities within the basin. A timeline showing significant historical events that impacted Silver Bow Creek and the upper Clark Fork River is shown in Figure 1-1.

Placer mining activities probably disturbed shallow ground-water aquifers, particularly along reaches of Silver Bow Creek and its tributaries near present-day Butte. Later, pumping of ground water from the underground mine workings dewatered the bedrock aquifer underlying the shallow alluvial aquifers.

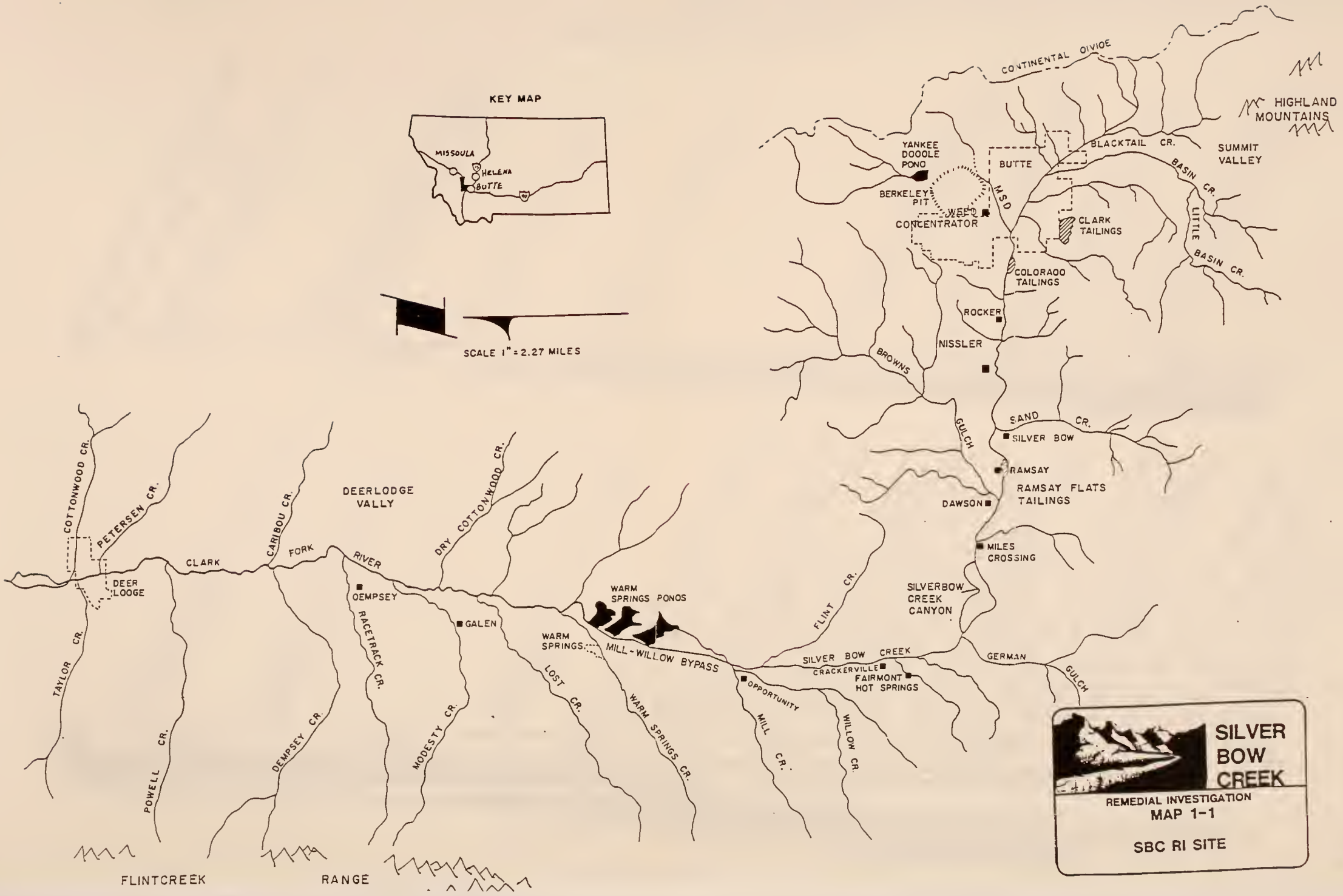
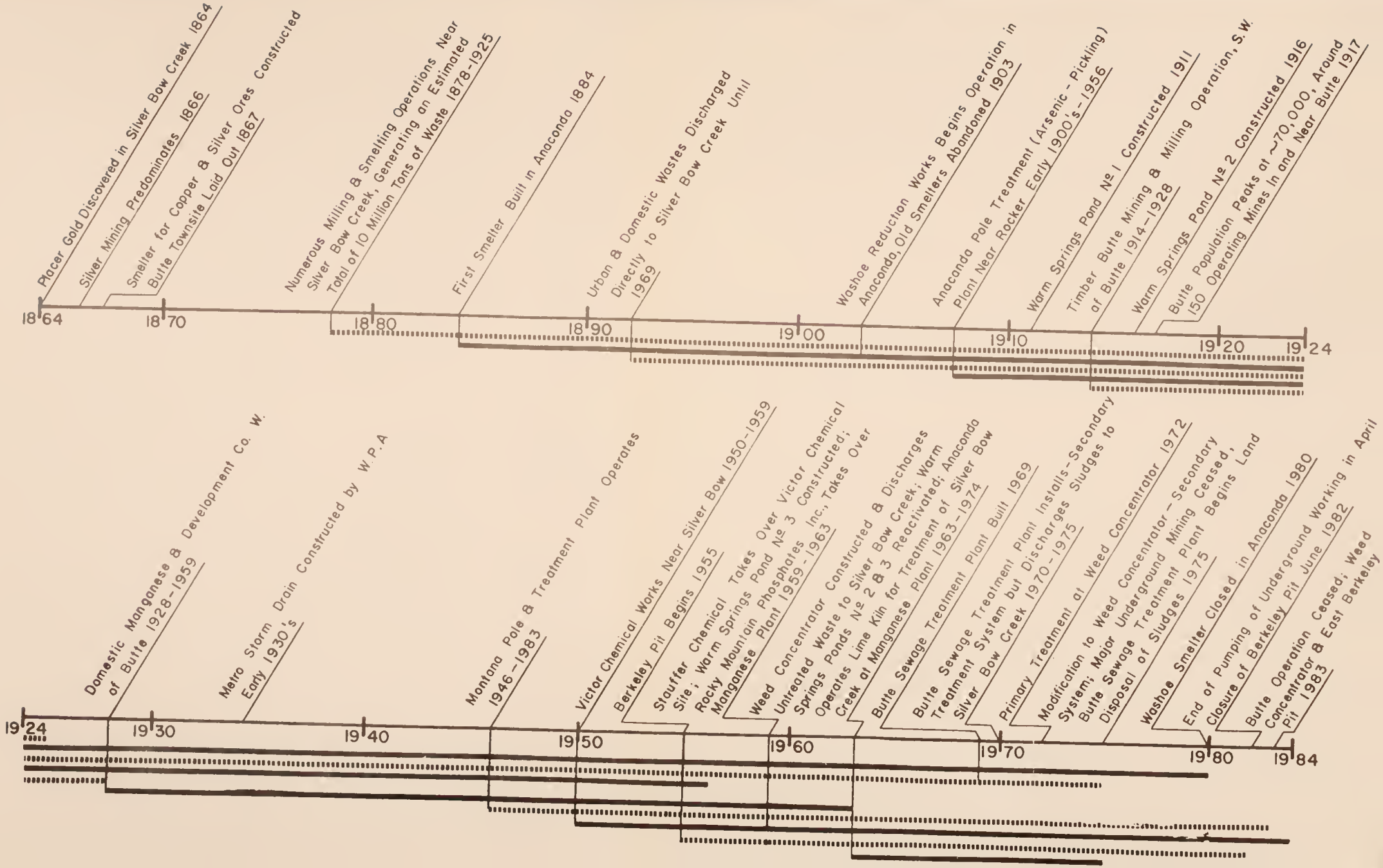

KEY MAP
MISSOULA
HELENA
BUTTE
SCALE 1" = 2.27 MILES
CONTINENTAL DIVIDE
HIGHLAND MOUNTAINS
YANKEE DOODLE POND
BERKELEY PIT
WWTP
CONCENTRATOR
MSD
BUTTE
BLACKTAIL CR.
SUMMIT VALLEY
BASIN CR.
LITTLE BASIN CR.
CLARK TAILINGS
COLORADO TAILINGS
ROCKER
NISSLER
BROWNS GULCH
SAND CR.
SILVER BOW
RAMSAY
RAMSAY FLATS TAILINGS
DAWSON
MILES CROSSING
SILVERBOW CREEK CANYON
FLINT CR.
GERMAN GULCH
SILVER BOW CREEK
CRACKERVILLE
FAIRMONT HOT SPRINGS
OPPORTUNITY
MILL CR.
WILLOW CR.
WARM SPRINGS PONDS
MILL-WILLOW BYPASS
WARM SPRINGS
WARM SPRINGS CR.
LOST CR.
MODESTY CR.
GALEN
OEMPSEY
RACETRACK CR.
DEMPSEY CR.
DEERLODGE VALLY
DRY COTTONWOOD CR.
CARIBOU CR.
CLARK FORK RIVER
COTTONWOOD CR.
PETERSEN CR.
DEER LODGE
TAYLOR CR.
POWELL CR.
FLINTCREEK RANGE
SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-1
SBC RI SITE

FIGURE 1-1

HISTORIC CONTAMINATION OF SILVER BOW CREEK


Placer Gold Discovered in Silver Bow Creek 1864
Silver Mining Predominates 1866
Smelter for Copper & Silver Ores Constructed
Butte Townsite Laid Out 1867
Numerous Milling & Smelting Operations Near Silver Bow Creek, Generating an Estimated Total of 10 Million Tons of Waste 1878-1925
First Smelter Built in Anaconda 1884
Urban & Domestic Wastes Discharged Directly to Silver Bow Creek Until 1969
Washoe Reduction Works Begins Operation in Anaconda, Old Smelters Abandoned 1903
Anaconda Pole Treatment Plant Near Rocker Early 1900's-1956
Warm Springs Pond Nº 1 Constructed 1911
Timber Butte Mining & Milling Operation, S.W. of Butte 1914-1928
Warm Springs Pond Nº 2 Constructed 1916
Butte Population Peaks at ~70,000, Around 150 Operating Mines In and Near Butte 1917
1864
1870
1880
1890
1900
1910
1920
1924
Domestic Manganese & Development Co. W. of Butte 1928-1959
Metro Storm Drain Constructed by W.P.A. Early 1930's
Montana Pole & Treatment Plant Operates 1946-1983
Victor Chemical Works Near Silver Bow 1950-1959
Berkeley Pit Begins 1955
Stauffer Chemical Takes Over Victor Chemical Site; Warm Springs Pond Nº 3 Constructed; Rocky Mountain Phosphates Inc., Takes Over Manganese Plant 1959-1963
Weed Concentrator Constructed & Discharges Untreated Waste to Silver Bow Creek; Warm Springs Ponds Nº 2 & 3 Reactivated; Anaconda Operates Lime Kiln for Treatment of Silver Bow Creek at Manganese Plant 1963-1974
Butte Sewage Treatment Plant Built 1969
Butte Sewage Treatment Plant Installs-Secondary Treatment System but Discharges Sludges to Silver Bow Creek 1970-1975
Primary Treatment at Weed Concentrator 1972
Modification to Weed Concentrator-Secondary System; Major Underground Mining Ceased; Butte Sewage Treatment Plant Begins Land Disposal of Sludges 1975
Washoe Smelter Closed in Anaconda 1980
End of Pumping of Underground Working in April Closure of Berkeley Pit June 1982
Butte Operation Ceased; Weed Concentrator & East Berkeley Pit 1983
1924
1930
1940
1950
1960
1970
1980
1984

Early smelting processes produced mill tailings which typically were deposited behind dams located in adjacent drainages or were discharged directly to Silver Bow Creek. These impoundments would occasionally fail, relasing large quantities of tailings downstream to lowlands and swamps below Butte (GCM Services 1983).

Although mining activities were suspended in this area during the RI, several possible sources still exist for continued water quality degradation of the system: tailings deposited in, and adjacent to, the surface waters; inflow of contaminated ground water; point-source discharges; and input from natural sources.

1.1 OBJECTIVES

Specific objectives of the Ground Water and Tailings Investigation were described in the SBC RI Work Plan (MultiTech and Stiller and Associates 1984):

- Determine general ground-water recharge/discharge conditions.
- Determine general rates and directions of shallow ground-water movement.
- Quantify spatial and temporal hydrochemistry of shallow ground water to distinguish between natural and contaminated waters.
- Quantify hydrologic relationships between shallow ground-water and surface-water systems.

- Confirm areal extent and thicknesses of tailings and other wastes along Silver Bow Creek and the Upper Clark Fork River.
- Quantify physical and chemical characteristics of tailings and related waste materials.
- Quantify unsaturated, vertical fluid movement through tailings and its effect on solute concentrations.
- Quantify temporal fluctuations of ground-water levels within saturated tailings and the resultant effects of solute concentrations.

The ground-water portion of the RI was completed in two phases. Phase I (December 1984 to May 1985) identified general hydrogeologic conditions in the study area to focus subsequent data acquisition. Phase II (November 1985 to January 1986) activities provided additional data at sites where more information was desired so that contaminant sources and migration processes could be better defined.

The tailings portion of the RI verified the extent and thickness of several mine and mill tailing deposits in the study area. The task also included an analysis of the hydrochemical interactions between tailings deposits and shallow ground-water systems. Additional tailings/soil sampling was performed in conjunction with drilling during Phase II ground-water activities.

Primarily, the following metals were studied: copper, zinc, iron, lead, arsenic, and cadmium. Other parameters were measured as

factors affecting the chemical behavior of metals: temperature, pH, Eh, dissolved oxygen, alkalinity, and total dissolved solids (TDS). Additionally, major cations and anions were determined: calcium, magnesium, sodium, potassium, sulfate, chloride, and fluoride. This report describes methods of measuring those analytes and presents the results and interpretations of those measurements. In addition, previous studies were examined to extend the data base.

1.2 SITE DESCRIPTION

The SBC RI study area extends from near the Weed Concentrator in Butte to near Garrison in the Deer Lodge Valley (Map 1-1). It is within the Northern Rocky Mountain physiographic province. The study area was limited to a corridor of land along major surface water courses approximately one mile on each side.

The central focus of the investigation is Silver Bow Creek and its downstream extension, the upper Clark Fork River. Tributary streams were investigated only to assess their impact on these two stream courses. The system drains a total of 1,005 square miles, measured at Deer Lodge (U. S. Geological Survey 1983).

1.2.1 Surface Hydrology

Silver Bow Creek begins in Butte, at the confluence of the Metro Storm Drain (MSD) and Blacktail Creek, as shown in Map 1-2 (Over Size). The MSD is an open channel that was constructed in the

early 1930s under the Works Progress Administration Program by realigning and filling the original Silver Bow Creek drainage. Today, the MSD has little or no flow except during storm runoff or snowmelt episodes. Blacktail Creek originates in the Highland Mountains about 15 miles south of Butte and drains approximately 75 square miles.

Silver Bow Creek flows west about 10 miles, into a canyon beyond Miles Crossing (Map 1-3 Over Size). Within this canyon the creek swings northward and flows for another 10 miles (Map 1-4 Over Size), terminating in the Warm Springs Ponds system.

The Warm Springs Ponds area is discussed in a separate report, Appendix C. The ponds were built as an effort to treat the contaminated water flowing in Silver Bow Creek, and therefore they are unique component of this system.

From the discharge of the Warm Springs Ponds, the stream course is called the upper Clark Fork River. The SBC RI follows the river to Garrison, where the study site ends (Map 1-5, Over Size).

The Butte Sewage Treatment plant (STP) discharges into Silver Bow Creek on the western edge of the city of Butte (Map 1-2 Over Size). Minor ephermeral tributaries discharging into Silver Bow Creek in its upper reaches include Missoula Gulch, Whiskey Gulch, Gimlet Gulch, and Sand Creek. Perennial discharges to Silver Bow Creek

include Browns Gulch, Silver Lake Discharge (during the RI period), and German Gulch.

1.2.2 Ground Water Hydrology

The ground-water system in the RI study area includes several water-bearing zones or aquifers. Generally, the water-bearing zones are present in three units: bedrock, unconsolidated deposits, and tailings deposits. The occurrence and hydraulic characteristics of these units is dependent on local geology and human activities in the region.

The bedrock aquifer in the vicinity of Butte is fractured and jointed within the quartz monzonite intrusives. This aquifer has been impacted significantly by historic dewatering activities at the Berkeley Pit, which have created a large cone-of-depression in the local ground-water system. Since 1982, when Anaconda Minerals Company (AMC) terminated dewatering activities, ground-water levels have been rising in the bedrock aquifer in recovery from the years of dewatering. Characteristics of the bedrock aquifer elsewhere in the study are largely unknown because of limited available data.

Unconsolidated deposits and associated aquifers are common throughout the study area and represent the aquifer most utilized for domestic purposes. The deposits are generally comprised of Tertiary valley fill and/or Quaternary alluvium. Characteristics of the unconsolidated material aquifers are highly variable within the

study area because of depositional and climatic history, geologic structure, and historic glaciation. Additionally, the Berkeley Pit has intercepted the Silver Bow Creek alluvial aquifer along the eastern third of the pit. Consequently, ground-water flow paths in the alluvial aquifer are impacted significantly in the vicinity of the pit.

Mine and mill tailing deposits are common throughout the study area. Some of these deposits are located along major streams and contain a shallow ground-water system, at least seasonally. Ground water in the tailing deposits is not used for domestic purposes but is significant because of possible impacts to receiving surface waters and adjacent or subjacent ground waters.

1.2.3 Climate

The study area has a continental climate, with annual precipitation averaging 11.5 inches in Butte and 13.2 inches in Anaconda. Climate in the higher elevations surrounding the study area is alpine to subalpine, characterized by colder temperatures and heavier precipitation (often in the form of snow). Melting of the mountain snowpack in spring and early summer provides the majority of the surface-water supply within the study area. Snow cover in the lower valleys usually melts in March to early April, with the mountain snowpack normally remaining through May and into June.

1.2.4 Geology

The geology underlying Silver Bow Creek ranges from Cretaceous intrusives and extrusives to Quaternary alluvium. The Boulder Batholith, in the eastern portion of the study area, is composed primarily of highly mineralized quartz monzonite. The Butte Mining District has been a major producer of gold, silver, and copper, and lesser quantities of cadmium, bismuth, aresenic, selenium, and tellurium (Miller 1973). The Deer Lodge Valley and the upper Clark Fork River are bounded on the west by the Anaconda-Pintlar and Flint Creek Ranges, which contain significant amounts of limestone. This distinct lithologic difference is reflected in soil character and influences surface- and ground-water chemistry in the Deer Lodge Valley.

1.2.5 Soils

A diversity of soil types are present in the study area. Soils in the basins are developed primarily on upland slopes under coniferous forests and on valley fill sediments under grassland vegetation. Adjacent to Silver Bow Creek and the Clark Fork River, shallow gravel-textured to deep fine-grained alluvial soils have developed. Nutrient-rich, organic soils of various depths are present in low or wetland areas.

Much of the natural soil in the study area has been affected by mining wastes such as mill tailings, smelter wastes, and stream-

deposited tailings. Mining-related wastes are generally sandy textured, reflecting their granitic origin, and typically have high concentrations of metals and sulfide minerals. In addition, Silver Bow Creek flows through two major mining and milling waste deposits: the Colorado Tailings, located near Butte, and a large waste flat located near Ramsay. Significant waste deposits of varying thicknesses are present along the entire course of Silver Bow Creek and the upper Clark Fork River.

1.3 PREVIOUS INVESTIGATIONS

1.3.1 Ground Water

Several ground-water and/or tailings investigations were completed in or adjacent to the Silver Bow Creek RI study area. Meinzer (1914) was one of the first to describe ground-water resources in the Butte area. Meinzer's study focused primarily on the alluvial aquifer in the Blacktail Creek Valley. Stout (1961) provided a general description of ground-water resources in alluvium east of the Berkeley Pit. Konizeski et al. (1961, 1962, and 1968) evaluated ground-water resources of the southern part of the Deer Lodge Valley. Botz (1969) examined ground-water quality and hydraulic characteristics in the Blacktail Creek alluvium.

Botz and Knudson (1970) examined ground-water characteristics in the east end of the Berkely Pit. U.S. Environmental Agency (USEPA) (1977) evaluated the geohydrology of the Silver Bow Creek area.

Hydrometrics (1980) evaluated ground water around AMC's Butte Operations. Hydrometrics (1983 a-h) completed an extensive data review and analysis of rehabilitation options for AMC, parts of which addressed ground-water resources. Duaime et al. (1982, 1984) described ground-water characteristics and reclamation construction alternatives for the Colorado Tailings area. Duaime (1983) also performed a ground-water investigation for the Butte-Silver Bow government for the sludge injection site located near Silver Bow.

The Montana Bureau of Mines and Geology (MBMG) installed a series of shallow ground-water monitoring wells along Butte's MSD during 1983. The wells are monitored in association with MBMG's on-going mine-flooding studies. AMC has collected ground-water data since 1982 from a series of monitoring wells in the Butte area. These data were submitted periodically to the Montana Department of State Lands (MDSL) Hardrock Bureau to fulfill permit requirements.

Many of the previous investigations were conducted in areas adjacent to the RI study area and, in many cases, contain little data directly applicable to this study. However, many aquifer characteristics identified in these previous studies can be extrapolated to the RI study area, and some water quality data apply directly to analysis of subsurface conditions at certain locales within the study area.

1.3.2 Tailings

Hydrometrics (1983 a-h) investigated the chemical and physical properties of tailings bordering Silver Bow Creek and the upper Clark Fork River (Map 1-1). Reclamation options for tailings-contaminated areas as well as related mining wastes were discussed. Schafer (1985) reported on first-year results of a study to re-establish pasture species on tailings-contaminated agricultural lands.

Limited data on extractable metal concentrations in tailings and buried soils were collected by the MBMG at the Colorado Tailings (Thornell 1985). Peckham (1979) measured total metal concentrations in tailings at several locations along Silver Bow Creek as part of a surface water hydrological investigation. A report by USEPA (1983) contains a limited amount of soil chemistry data from sediments collected along Silver Bow Creek at selected locations. Rice and Ray (1984) examined the Grant-Kohrs ranch area north of Deer Lodge, and Osborne *et al.* (1986) reported on agricultural lands adjacent to Silver Bow Creek.

1.3.3 Data Deficiencies

This RI fills several data gaps in the previous studies. None of the earlier ground-water studies collected water quality samples from closely spaced stations within the study area. Determination of the extent of the contaminated ground water and the possible

sources of contamination requires many wells in close proximity and analyses for a variety of metals and anions. Previous tailings studies generally did not include studies on the interactions of ground water and tailings deposits. In addition, none of the available tailings data are known to have sufficient documentation through a quality assurance program to fully verify the data. The studies on the Colorado Tailings were determined to be adequate and this deposit was excluded from this phase of the RI.

2.0 METHODS

Methods employed during the Ground Water and Tailings Investigation of the Silver Bow Creek Remedial Investigation (SBC RI) are the same as those described in the SBC RI Work Plan (MultiTech and Stiller and Associates 1984). This section describes historic data evaluation, field investigation methods, and data analysis and interpretation techniques. Where methods differed from those described in the Work Plan, appropriate justification is provided.

2.1 HISTORIC DATA COLLECTION AND EVALUATION

Historic ground-water and tailings data were collected from several sources, such as various state and Federal agencies, published and unpublished reports, and the Anaconda Minerals Company (AMC). Ground-water data included the locations and physical characteristics of existing domestic and monitoring wells, ground-water quality and static water level data, and limited aquifer test data. Tailings data included maps of tailings extent and thickness, tailings chemistry, and descriptions of physical characteristics of tailing deposits.

Criteria for entering historic data in the computerized data base were as follows: (1) verification of sample location and sampling agency/individual; (2) location of sampling site relative to areas of interest; (3) for ground-water data, an available lithologic drilling log for the well; and (4) completion of analyses by

an identifiable laboratory. Historic ground-water data is included in Attachment I.

The compiled historic data then were compared to U.S. Environmental Protection Agency (USEPA) criteria for data acceptance. The USEPA has two levels of Data Reliability Criteria which have separate documentation requirements. Level A documentation requires the sampling date, location, and team; sample collection, preparation, and preservation techniques; shipping and analysis dates; laboratory preparation and analytical methods; and detection limits. Level B criteria include all the criteria listed for Level A, plus quantitative statistical control samples, chain-of-custody control documents, and proper USEPA sampling and analysis protocol.

Data which meet Level A requirements only may be used to help direct the RI study. Data meeting Level B constraints can be included with RI-generated data for evaluating risks or remedial alternatives.

2.1.1 Ground-Water Inventory

A great number of domestic, livestock, irrigation, and monitoring wells exist within the Summit and upper Deer Lodge Valleys, but only those suspected to be impacted by contamination were inventoried. Physical characteristics and locations of wells were obtained from the following sources: Montana Department of Natural Resources and Conservation (MDNRC) - Water Rights Bureau; Montana Bureau of Mines and Geology (MBMG); Montana Department of Health

and Environmental Sciences (MDHES); U.S. Geological Survey (USGS); U.S. Soil Conservation Service (SCS); county courthouses in Silver Bow, Deer Lodge, and Powell Counties; Anaconda Minerals Company (AMC); Stauffer Chemical Company; Tetra Tech; and local water well drillers.

Field surveys verified the location of the wells and found previously unidentified wells. Several physical characteristics of the wells (total depth, static water level, diameter, present owner, etc.) also were checked. All well data collected were compiled and input to the computerized data base. The well inventory generated is listed in Attachment II.

2.1.2 Aquifer Test Data

Available aquifer test data for sites within the study area were sought from MBMG, AMC, USGS, MDSL, and local well drillers. These data were evaluated with respect to study objectives, test methodology employed, and the location relative to areas or aquifers of interest.

Historic aquifer test data applicable to the RI study included that presented by Botz (1969), Konizeski et al. (1968) and Duaime (1983). Other information which proved useful was obtained from well driller's logs.

2.2 FIELD INVESTIGATION

Ground-water and tailings field investigations were conducted to provide additional data in areas where insufficient information was available to define the extent and severity of contamination. Several work tasks were performed: monitoring well and vadose zone monitoring installations; ground-water level monitoring; ground-water and vadose zone sample collection; aquifer testing; and tailings and material sampling.

2.2.1 Installation of Ground-Water Monitoring Wells and Equipment

Fifteen monitoring wells (GS-01 through GS-06, TS-01 through TS-07, TS-12, TS-13) were installed during December 1984 (Phase I). Ten additional monitoring wells (GS-07 through GS-15) were installed in November and December 1985 (Phase II). Locations of all monitoring wells sampled during the RI are shown on Maps 1-2, 1-3, 1-4, and 1-5 (Over Size). Smaller-scale, more detailed maps of the MSD area and upper Silver Bow Creek which show well locations more clearly are presented in Maps 2-1 and 2-2. Lithologic and completion logs of the monitoring wells constructed during the RI are contained in Attachment III.

Locations, depths, and types of monitoring wells installed were selected using the following criteria:

- Locations of potential sources of contamination;

△ GS-14 Monitoring Well No.
(60) Total Depth (ft.)

0 1150' 2300'

BERKELEY PIT

DW-101 (90)

Continental Drive

Weed Concentrator

DW-102 (65)

DW-103 (67)

Civic Center Road

GS-07 (160)

GS-10A (110)

DW-105 (47)

GS-10B Drain (29)

DW-106 (101)

DW-107 (55)

DW-108 (17)

DW-110 (12)

DW-109 (18)

DW-115 (26)

DW-117 (18)

DW-116 (34)

DW-114 (14)

Storm Metro

George St.

DW-111 (18)

DW-112 (16)

DW-113 (17)

GS-14 (62)

GS-08 (146)
GS-09 (76)
GS-11 (18)

DW-118 (28)

DW-119 (17)

DW-121 (12)

DW-131 (35)

Front Street

Kaw Avenue

Montana Street

Blacktail Creek

Harrison Avenue

MAP 2-1

LOCATIONS AND
TOTAL DEPTHS OF MONITORING WELLS
IN THE MSD AREA

△ GS-14 Monitoring Well No.
(60) Total Depth (ft.)

Travona

0 1000 2000'

APPROX. EXTENT OF UNCONSOLIDATED MATERIAL

Missoula Gulch

Street

Avenue

Centennial

Silver Bow Creek Tailings

Colorado

Interstate 90

Montana

Creek

DW-127 (9)
DW-130 (20)
DW-128 (65)
DW-135 (19)
DW-138 (20)
DW-132 (24)
DW-134 (16)
DW-136 (15)
DW-137 (10)
GS-12 (30)
GS-13B (34)
GS-13A (18)
DW-131 (35)
GS-15A (32)
GS-15B (15)
DW-121 (12)
DW-122 (29)
DW-124g (16)
DW-133 (17)
DW-123 (37)
DW-125 (37)

MAP 2-2
LOCATIONS AND
TOTAL DEPTHS OF MONITORING
WELLS IN UPPER SILVER BOW
CREEK

- Proximity, depths, and physical characteristics of existing wells (i.e., type of construction, perforated interval, data reliability, etc.);
- Results of Phase I ground-water investigation (Phase II wells);
- The need to correlate stratigraphy and lithology;
- The need to characterize general and site-specific hydrogeologic conditions; and
- The need to determine and characterize the vertical and areal extent of contamination.

2.2.1.1 Monitoring Well Installation

A cable tool drill rig was utilized for monitoring well installations. The drill rig was decontaminated prior to set-up and at the end of drilling activities at each drill hole. Decontamination procedures used are described in Attachment IV.

A split-spoon core sampler was used during drilling activities to obtain sub-surface material samples at discrete intervals. All material-sampling apparatus received appropriate decontamination between sample collection episodes in accordance with procedures described in Attachment IV. Material samples were subsequently bagged and delivered to the laboratory for analysis.

The general drilling procedure involved churning material with the cable tool and bailing cuttings with a sand bailer. The cuttings were logged by an on-site hydrogeologist; selected samples were

bagged and archived for future reference. Six-inch steel casing was driven into the boring to minimize borehole collapse. The lower 2 feet of the steel casing was perforated, which allowed sampling water from discrete intervals. The collected water samples were promptly analyzed for field parameters. This procedure proved valuable in determining poor-quality zones in the ground-water system and in identifying perforated intervals and total depths for monitoring well casings.

All monitoring wells constructed during the RI were developed to remove drilling debris from the borehole. Development also was performed to enhance the effectiveness of the sand pack around the perforated portion of the casing in bridging fine-grained sediment out of the well. Two methods of well development were utilized during the course of the investigation: compressed-air and surge blocks. Decontamination procedures used for well development equipment are described in Attachment IV; well development field forms are contained in Attachment III.

The compressed-air development technique involved surging the hole using a 100 cfm (cubic feet per minute) air compressor. The air was directed into the monitoring wells through a hose, which was connected to a perforated PVC pipe placed in the well. Water in the wells was evacuated intermittently using this technique for a period of time until the discharge appeared clean and essentially sediment free. In some cases, the compressed-air development technique was inappropriate due to a lack of water in the monitoring wells or

because the material surrounding the sand/gravel pack was too fine. In these cases, surge blocks were utilized to develop wells, which involved inserting a solid cylinder (surge block) into a well of similar diameter. The surge block was plunged up and down near the perforated interval of the well for a period of time. Water in the well was removed with a hand bailer and the well was allowed to recover. The process was repeated until clear water was evacuated.

All monitoring wells constructed during the RI and several existing wells were surveyed by a licensed surveyor to determine elevation. Reference elevation points utilized during the survey were either U.S. Geological Survey bench-marks, National Geodetic Survey bench-marks, or control points from previous surveys. Survey data gathered during the RI are contained in Attachment II.

Single Wells

Single well construction was completed at several sites in the study area. The construction consisted of placing decontaminated 4-inch, schedule-40, flush-threaded PVC casing into a 6-inch borehole. The casing was factory-slotted in the zone(s) of interest. Chemically-inert silica sand was placed between the steel casing and PVC and adjacent to the perforated interval.

The steel casing was pulled back in sections by utilizing hydraulic jacks and/or the drill rig to expose the PVC casing to the borehole. A bentonite plug was used to seal the annular space about the PVC

above the perforated interval. Backfill consisted of pea-gravel in the saturated, non-perforated interval and drill cuttings in the unsaturated portion of the borehole. The steel casing was pulled completely out of each hole, and the well annulus was sealed with cement overlying bentonite. A locking well protector was installed over the PVC casing. Figure 2-1 depicts the final single-well design utilized during the investigation.

Dual Wells

Dual completion monitoring wells were constructed at selected sites. This procedure was similar to that described for single-well construction except that two 2-inch, decontaminated PVC casings, perforated at different depths, were installed in the 6-inch borehole. The interval between the perforated sections of the two casings was packed with bentonite to establish hydraulic separation between the two water-bearing zones. Figure 2-2 is a schematic of the dual completion monitoring well design used during this investigation.

2.2.1.2 Vadose Zone Monitoring Equipment Installation

Vadose zone monitoring equipment consisted of porous cup lysimeters for sample acquisition and tensiometers to measure soil water pressure. All equipment and materials used during the installation process were decontaminated as described in Attachment IV.

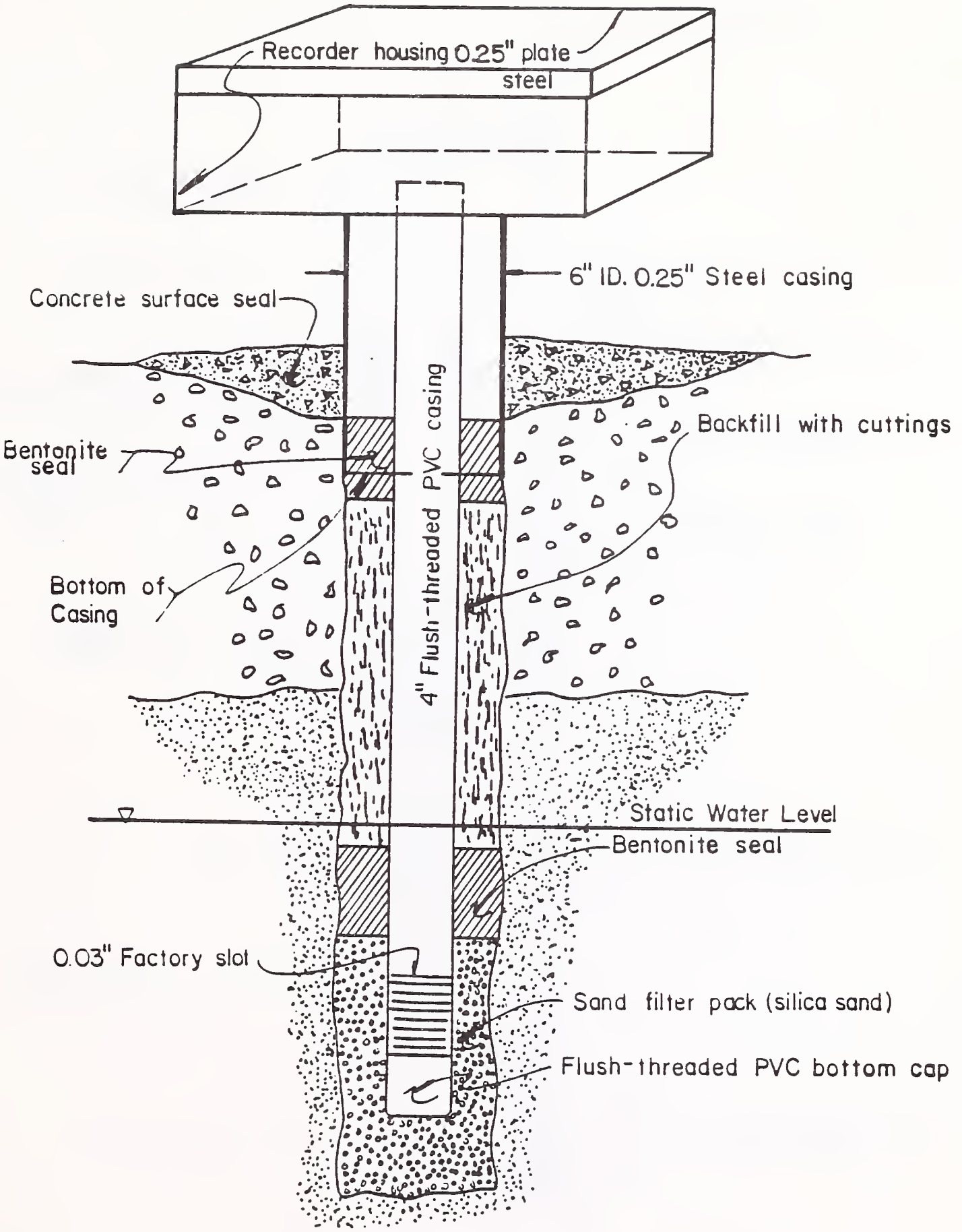


FIGURE 2-1

TYPICAL SINGLE MONITORING WELL CONSTRUCTION
(NOT TO SCALE)

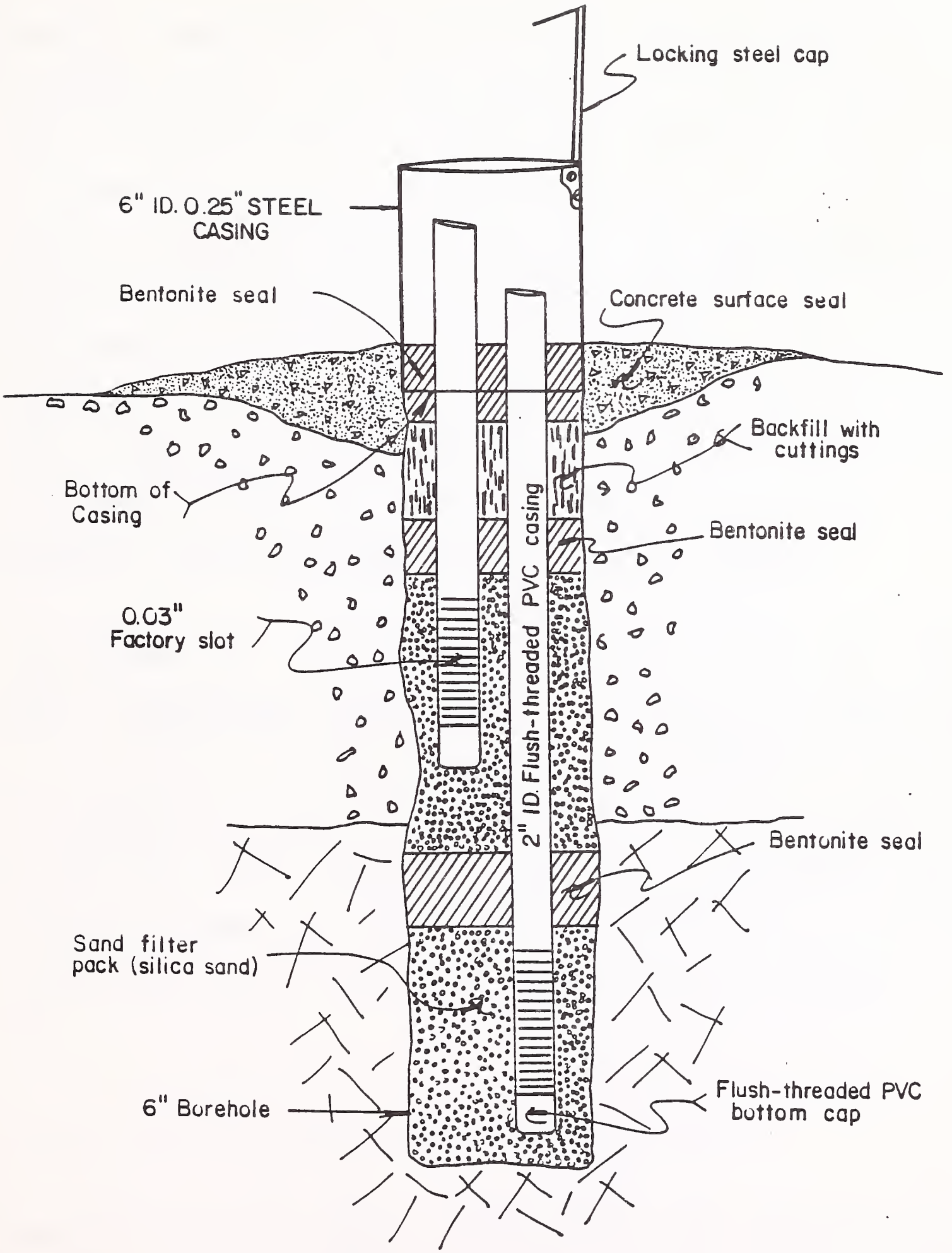


FIGURE 2-2

TYPICAL DUAL MONITORING WELL CONSTRUCTION

(NOT TO SCALE)

Lysimeter installation involved boring a hole to a desired depth by utilizing either a cable tool drill rig or a hand-operated soil auger. A silica flour/deionized water slurry was poured into the boring and the porcelain bottom cup of the lysimeter was placed into it. Bentonite and drill cuttings then were placed above the silica slurry and about the lysimeter stand pipe. The installation was completed with a locking housing and cement surface seal in the lysimeter annulus. Figure 2-3 depicts a typical lysimeter installation. Installation and lithologic logs for lysimeters are contained in Attachment III. Initially, two lysimeters did not function properly; one was reinstalled at a different location.

Tensiometers were installed using a special tool that created a hole to emplace the device. They were filled with a water-ethylene glycol mixture to prevent freezing. Soil tension was measured in the tensiometers periodically during the frost-free period of the RI, to the nearest one-quarter centibar. Tensiometer lithologic description logs are contained in Attachment III. A schematic diagram depicting a tensiometer installation is shown in Figure 2-4.

2.2.1.3 Neutron Probe Access Tube Installation

Twenty-five neutron probe access tubes were installed at three locations: near Silver Bow, near Rocker, and at Ramsay Flats (Maps 2-3, 2-4, and 2-5, respectively). All tubes were installed with a truck-mounted hydraulic probe with a King Tube-type 2-inch barrel

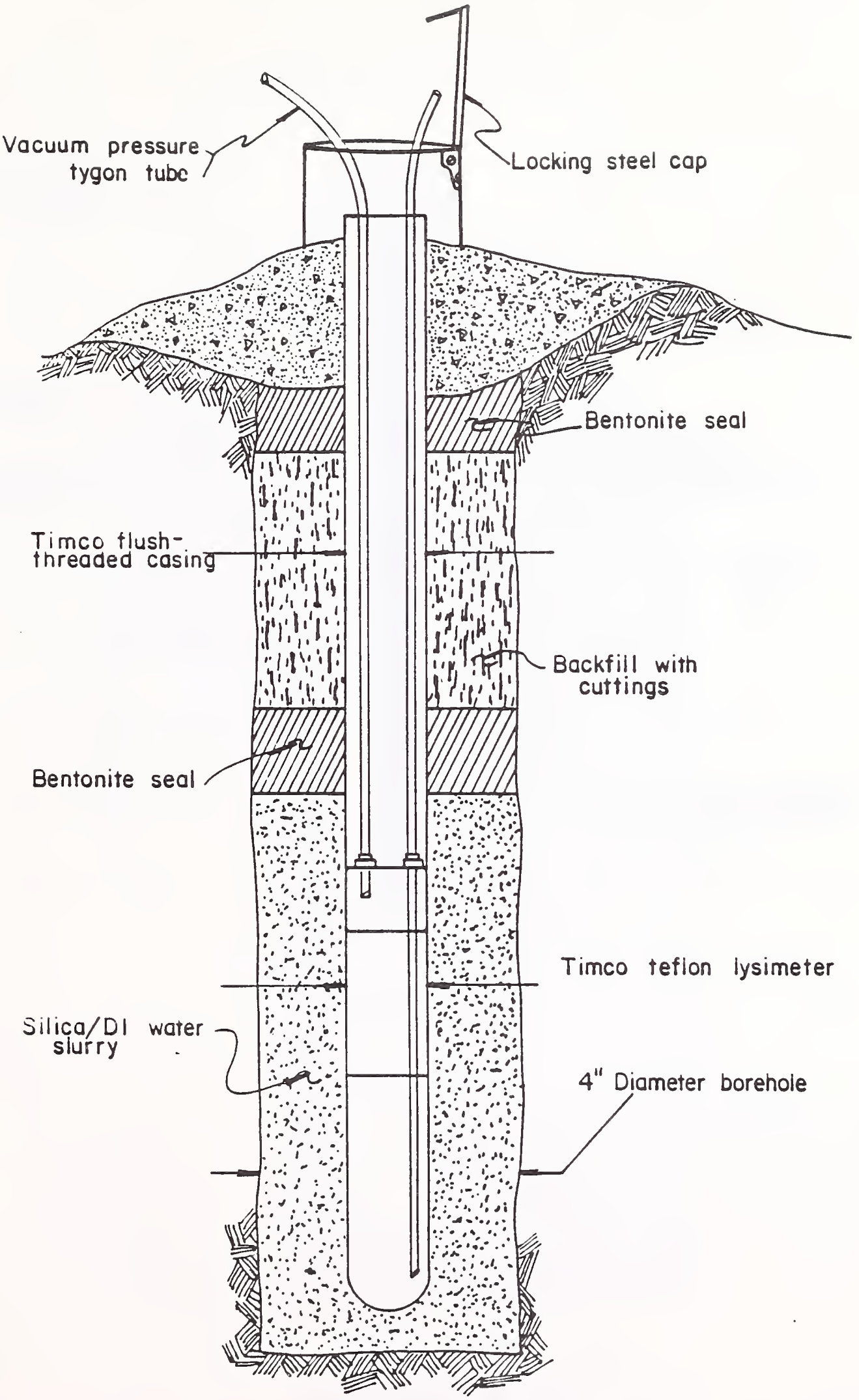


FIGURE 2-3

TYPICAL LYSIMETER INSTALLATION

(NOT TO SCALE)

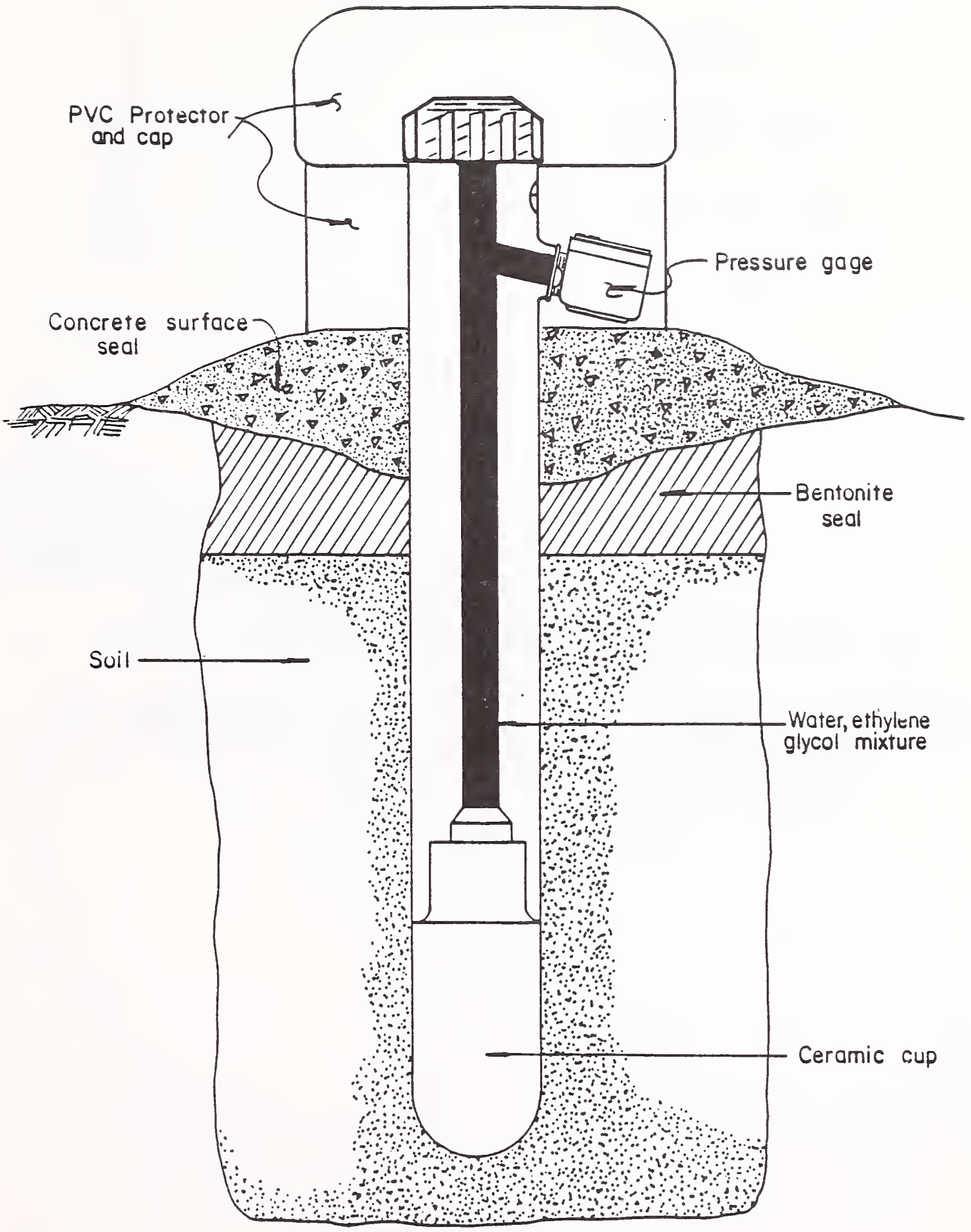
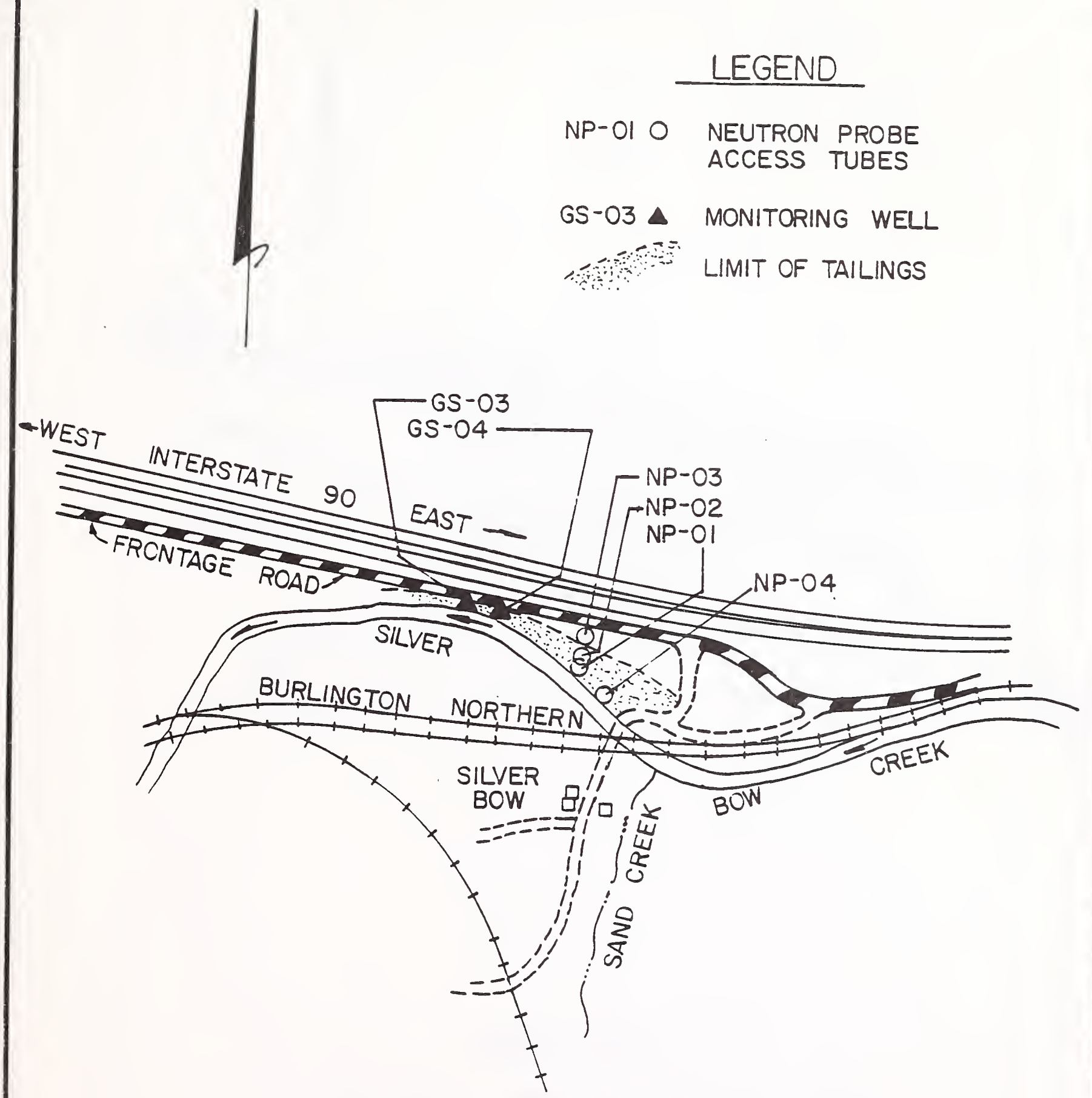


FIGURE 2-4

TYPICAL TENSIOMETER INSTALLATION

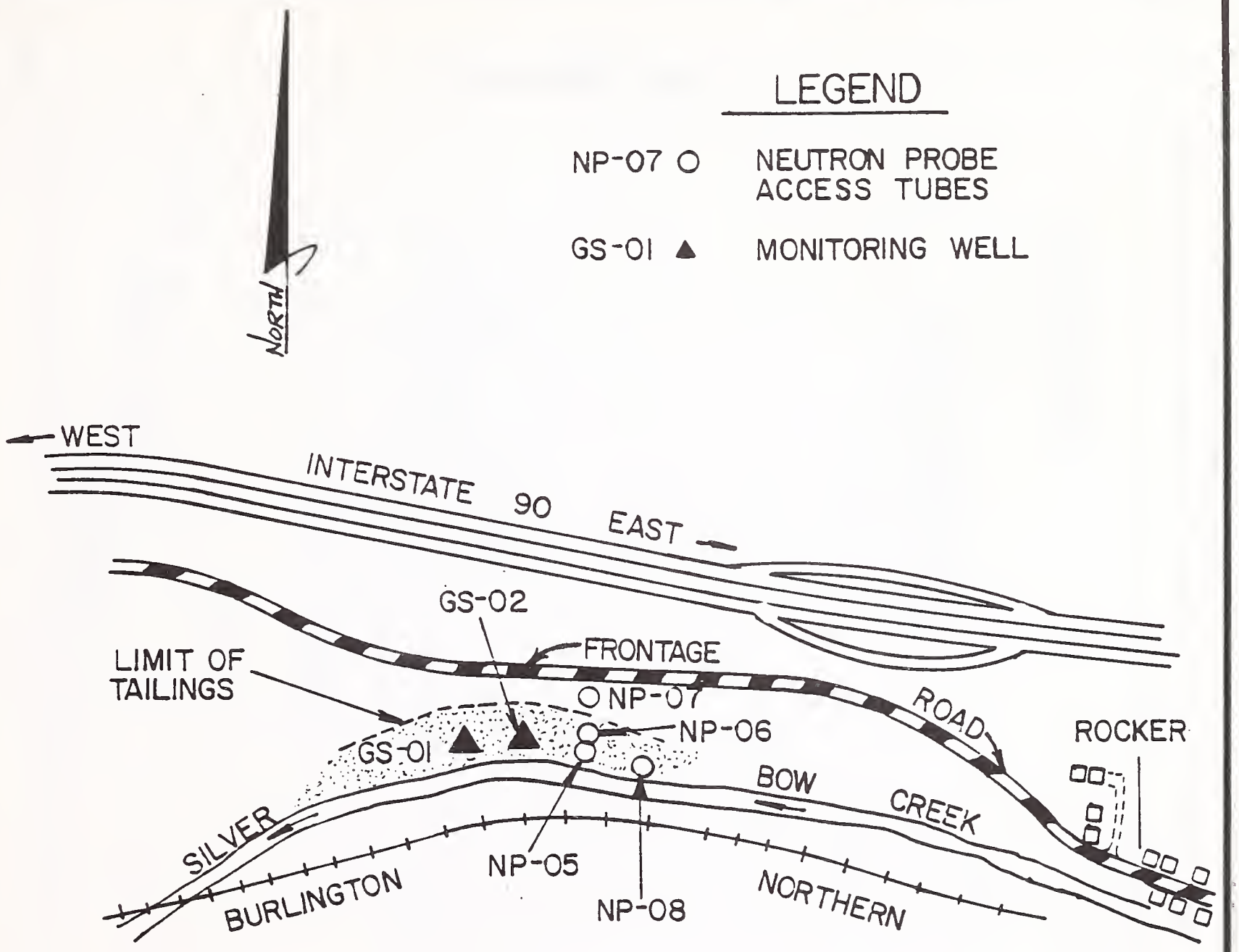
(NOT TO SCALE)



MAP 2-3

NEUTRON PROBE ACCESS TUBE LOCATIONS NEAR SILVER BOW SIDING: SILVER BOW CREEK RI

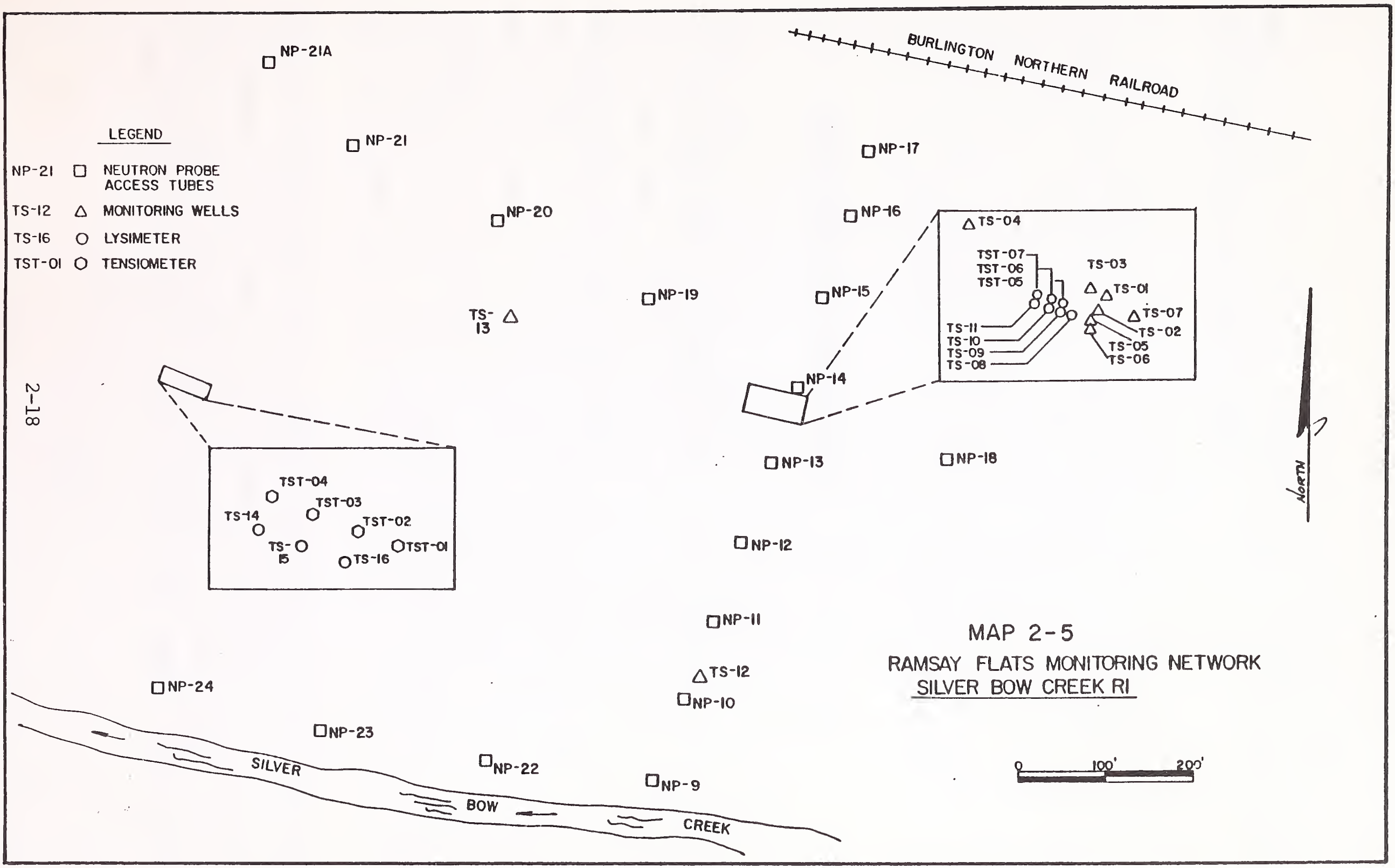
(NOT TO SCALE)



MAP 2-4

NEUTRON PROBE ACCESS TUBE LOCATIONS NEAR ROCKER: SILVER BOW CREEK RI

(NOT TO SCALE)



MAP 2-5

RAMSAY FLATS MONITORING NETWORK
SILVER BOW CREEK RI

sampler. Logs of subsurface layers were recorded at each tube installation site (Attachment III).

Initially, aluminum 2-inch irrigation pipe was used as neutron access tubes at each site, but the pipe had a 0.51-inch wall thickness which tended to bind the radioactive source instrument. Subsequently, all aluminum tubes were replaced with a 2-inch galvanized steel thin-wall electrical conduit to avoid binding. Results using the galvanized steel tubing were satisfactory.

2.2.2 Ground Water Level Monitoring

Static water levels were measured in various wells periodically from December 1984 to December 1985, and Attachment V presents static water level data collected during the RI. Static water levels were measured using electric well probes, and measurements were made to the nearest 0.1 foot from a designated measuring point on each well. The same set of well probes were used to measure all wells throughout the investigation. All well probes were regularly calibrated to a steel tape in accordance with the Quality Assurance/ Quality Control Plan (MultiTech and Stiller and Associates 1985).

Special efforts were made to obtain ground-water level measurements at domestic wells during times of minimal ground-water use by residents. Appropriate notations were made when measurements reflected suspected pumping water levels rather than static water levels.

Recorders were installed at six monitoring wells (GS-01 through GS-04, TS-01, and TS-02) (Map 1-3 Over Size) to obtain a continuous record of ground-water elevation. They utilized a float, counter weight, and electronic recorder, and the data storage modules were decoded using a data pod/cassette reader. Continuous-record data of water level elevation of selected wells are contained in Attachment V.

During winter months, a few problems were encountered in obtaining water level records from shallow monitoring wells: frozen ground water in the casings which disrupted data collection; and frost heaving of casing protectors that affected measuring point elevations. Appropriate documentation and adjustments were made to account for these occurrences.

2.2.3 Sample Collection and Analysis

The dates of ground-water and vadose zone sampling are presented in Attachment VI. The sampling network consisted of 70 existing wells, plus 26 monitoring wells and 7 lysimeters constructed during this RI.

Tailing, mining wastes, and associated soil materials were described and sampled at a number of locations in the project area to estimate the range of contaminant levels found in the site. Solid material sampling sites are shown on Maps 1-2, 1-3, 1-4, and 1-5 (Over Size).

Sampling methodologies were in accordance with those described in the Silver Bow Creek RI Work Plan (MultiTech and Stiller and Associates 1984). All data collected during the RI are contained in Attachment VI. Decontamination procedures utilized during sample collection, field parameter measurement techniques, and descriptions of sample preparation, handling, packaging, sample custody, and documentation are given in Attachment IV.

2.2.3.1 Ground Water

Prior to sampling ground water from a well, approximately three bore volumes of water were evacuated using a PVC bailer. Domestic wells were evacuated using existing submersible pumps. Indicator parameters (temperature, conductivity, and pH) were monitored for consistency during the evacuation process.

Several monitoring wells had inadequate inflow to allow evacuation of three bore volumes. These wells were bailed dry before the required volume of water was removed, and sampling commenced during or following recovery of the well.

Water samples were collected from monitoring wells with a decontaminated bailer during Phase I sampling and with a bladder pump during Phase II sampling activities. Sample water from the bailer or bladder pump was directed into a sample container. Domestic well samples were collected from a discharge line and on the well side of any water-conditioning device.

2.2.3.2 Vadose Zone

Sample collection from the vadose zone was performed by applying a vacuum to the porous cup lysimeters and using a pinch-cock to maintain a negative pressure of approximately 18 pounds per square inch (psi) on the system. This setup operated for at least 24 hours, and up to one week, prior to sample collection.

Positive pressure then was applied to the lysimeter at approximately 5 psi, which forced the collected sample to the surface. The sample was collected in a decontaminated beaker which was used to transfer the sample to appropriate sample containers and to perform field tests. Prior to sampling each lysimeter, at least three volumes of fluid were evacuated to dewater the silica flour slurry. Chemical analyses of lysimeter samples are presented in Attachment VI.

2.2.3.3 Solid Materials

Samples were collected along Silver Bow Creek beginning below the Colorado Tailings and extending to Miles Crossing (Maps 1-2 and 1-3 Over Size). Additional locations were sampled along the upper Clark Fork River and on agricultural lands in association with the Agriculture Investigation (Appendix D, Part 3) (Maps 1-4 and 1-5 Over Size).

Detailed soil profile descriptions were made at each sample location. Field soil morphological and descriptive site information were encoded into a soil information system (Attachment III) to assist in interpretation of laboratory data.

Samples of tailing and underlying soils were collected at each location. Soil horizons or depositional layers of tailings were described by depth in the field. Requisite QA/QC field samples and sample splits were introduced to the sample train, and appropriate chain-of-custody procedures were followed.

Ground-water and vadose zone water samples were passed through a 0.45 micron filter prior to preservation and analysis. Analytical parameters for water samples are listed in Table 2-1. RI Water Quality Data is presented in Attachment VI.

Solid materials were air-dried and pulverized in a flail-type mill. Material passing a <2mm hole-size sieve were retained for analysis, and the amount of material greater than 2mm was measured on a gravimetric basis. A list of analytical methods used to characterize soil chemical and physical properties of tailings is shown in Table 2-2. Resultant analyses from tailings and soil samples, metals partitioning data, and agricultural lands sample analyses are presented in Attachment VI.

TABLE 2-1
GROUND WATER AND VADOSE ZONE WATER
PARAMETER LISTS

Ground Water	Vadose Zone Water
Static Water Level	Sample Volume
Temperature	Temperature
Specific Conductivity	Specific Conductivity
Eh	pH
pH	Sulfate
Dissolved Oxygen	Alkalinity
Sulfate	Chloride
Alkalinity	Fluoride
Chloride	Calcium
Fluoride	Magnesium
Calcium	Sodium
Magnesium	Copper (a)
Sodium	Arsenic (a)
Potassium	Zinc (a)
Copper(a)	Iron (a)
Arsenic(a)	Cadmium (a)
Zinc(a)	Lead (a)
Iron(a)	
Cadmium(a)	
Lead(a)	
Total Dissolved Solids (TDS)	

Note:

(a) dissolved constituents only

TABLE 2-2
TAILINGS AND SOILS
ANALYTICAL PARAMETER LIST

Parameter	Analytical
pH	1:1 water, combination pH electrode
Specific Conductance (Micromhos/cm)	paste, conductance bridge
Mechanical Analysis	modified hydrometer (Sobek et al. 1978)
Rock (> 2mm fraction %)	Gravimetric
Saturation Extract	Paste method (Richards 1954)
saturation	
Ca, Mg, Na, K (meq/L)	ICP
SAR	$Na/(Ca+Mg)/2)^{0.5}$
Cd, Cu, Fe, Mn, Pb, Zn (mg/kg)	ICP, graphite cell AA
1.0 N Ammonium Acetate Extract	
pH 5.5	Methods of Soil Analysis, #2
K	ICP
SO_4	turbidimetric
Cd, Cu, Fe, Mn, Pb, Zn (mg/kg)	ICP, graphite cell AA
Nitric Peroxide Digest (TOTAL)	USEPA, CLP procedure
Cd, Cu, Fe, Mn, Pb, Zn	ICP, graphite cell AA
NO3-N	2:1 (water soil) extract specific ion electrode
Arsenic	Olsen ($NaHCO_3$) or Bray (NH_4F+HCl)
Phosphorus	Olsen ($NaHCO_3$) or Bray (NH_4F+HCl)
Molybdenum	acidified ammonium oxalate
Total S	LECO analyser
Sulfide S	serial HCl extraction, LECO

Saturation and Ammonium acetate extract solutions were treated with nitric acid preservation to maintain metals in solution. Iron precipitation was noted to occur without the preservation in some samples.

2.2.4 Aquifer Testing

Aquifer tests were performed on the following monitoring wells, installed during this RI: GS-01, GS-03, GS-07, GS-08, GS-09, GS-13B, and TS-01 (Maps 1-2 and 1-3 Over Size). Each test was performed by pumping the wells with a submersible pump at a constant rate and monitoring water level decline in the pumped well and any adjacent observation wells.

Discharge from the pumped well was typically monitored using a barrel manometer. Water levels in the pumped well and in any adjacent observation wells were monitored with a combination of pressure transducers and electric well probes. Water level measurements were made in discrete time intervals with more frequent measurements during the early stages of the tests. During each aquifer test, field parameters (specific conductivity, pH, and temperature) were measured periodically.

Before each aquifer test, the wells were pumped for up to two hours to further develop the wells and to ensure the discharge rate used would sufficiently stress the aquifer, given the amount of available drawdown. Prior to the start of the test, the wells were allowed to recover to their original static water levels. The constant discharge tests were continued until general aquifer hydraulic characteristics were identified and quantified. Most pumping tests were 4 to 6 hours long; one lasted 24 hours. Following the pumping

tests, water level recovery data were obtained. Water level measurements were obtained more frequently during the time period immediately following pump shutdown. Recovery was monitored until the pumping well had returned to within 5% of its pre-pumping water level. Attachment V contains aquifer test data collected during the SBC RI.

2.2.5 Soil Water Content Measurements

Soil water content readings were made with a Campbell Pacific Nuclear Model 503 neutron probe utilizing a 50 mCi Americium 251 - Beryllium sealed neutron source/detector. Water content was measured every two to four weeks from May through August. Three to five shield counts were made at each tube. Field neutron counts were made for 15 seconds at 15 cm increments to the base of the access tube (typically 215 cm).

Volumetric soil water content was determined by comparing the field to shield count ratio to an on-site calibration curve relating count ratio to measured gravimetric water content. A soil density of 1.4 g/cm^3 was assumed to convert from gravimetric to volumetric water content. Different calibrations were necessary for the aluminum and galvanized iron pipe due to differences in neutron attenuation of the two materials. Calibration curves derived are shown in the following equations:

Aluminum Pipe:

Water Content (g water/cm^3 soil) = .044 + .261 * (CR)

Galvanized Pipe:

Water Content (g water/cm^3 soil) = .027 + .334 * (CR)

Where:

CR is the count ratio

Neutron probe data (Attachment V) were encoded in a computer program to automatically calculate average shield counts, water content in weight fraction and inches of water per foot, and net change in water content between dates of measurement.

2.3 DATA ANALYSIS

The SBC RI study area was divided into subareas for the Ground Water and Tailings Investigation, based on unique hydrogeologic features. This division aided in evaluating specific portions of the study site. The subareas initially were analyzed separately, and then in concert, to provide a conceptual hydrogeologic model of the entire Silver Bow Creek RI study area.

The QA/QC Plan prepared for the Silver Bow Creek RI (MultiTech and Stiller and Associates 1985) was closely followed. The QA/QC plan provides guidance in the following areas:

- Field procedures;
- Analytical laboratory protocol;
- Chain-of-custody procedures; and
- Data QA checks, including field measurement duplicates (flow, pH, SC, temperature); field blanks and duplicate samples; sample bank blanks, spikes, standards, and splits; laboratory blanks, spikes, calibration checks, and replicates; and referee laboratory duplicates.

Data generated during this RI were subjected to the rigorous Level B Data Reliability Criteria described previously in Section 2.1, and were considered validated if these criteria were met. The SBC RI Laboratory Quality Assurance/Quality Control Program (Appendix F) contains a more detailed QA/QC discussion.

2.3.1 Ground Water

The lithology and associated geology of each area were analyzed for physical characteristics germane to evaluation of the ground-water system and its interaction with surface waters. This analysis included review of available and appropriate literature, supplemented by site-specific information obtained during RI drilling activities.

Lithologic and structural cross-sections and longitudinal profiles were created to portray portions of the study area. When possible, correlations were made laterally to depict stratigraphic continuity.

Ground-water quality data were evaluated both by changes in concentrations over time at an individual well and concentration gradients observed at many wells at one time. Plots of parameter concentrations over time were used to evaluate temporal variations in water chemistry. Stiff diagrams and trilinear diagrams were used to evaluate water quality changes spatially within a study subarea and between adjacent subareas. Isopleth maps were used to evaluate the spatial distribution of several water quality parameters. Finally, an evaluation of water quality data was made regarding the severity of contamination by comparing data to Federal drinking water standards.

Historic and RI ground-water level data also were analyzed both spatially and temporally. Graphs or plots of water levels were used to evaluate seasonal fluctuations from both periodic and continuous water level measurements. Potentiometric maps were produced to evaluate changes in water-table elevation within a given aquifer or within a specific geographic area and to interpret flow directions and gradients in the study area.

Aquifer tests were evaluated by creating time-drawdown and time-recovery plots from the pumping data. These plots were analyzed for both pumping wells and observation wells in accordance with published methods in the literature. Resultant data also were evaluated qualitatively with respect to vertical responsiveness of adjacent shallow wells to pumping from deeper water-bearing zones,

which was important in deciphering the degree of hydraulic connection between various zones in the aquifer.

A conceptual hydrogeologic model of individual study units was completed, incorporating many of the foregoing analyses. Both physical and chemical evaluations of the ground-water system were developed to summarize contaminant processes occurring within each subarea and between subareas.

2.3.2 Tailings

Tailings, soils, and geologic material analyses were reviewed to determine the presence of inorganic contaminants and also to identify the relative mobility of each element. Where possible, mechanisms controlling solubility, flux, and transport of metals were identified or conceptualized. Observed metal concentrations were compared to general geochemical background levels found in the literature.

A variety of graphical and statistical interpretive techniques were used to assist in these analyses. Logarithmic transformations of skewed data were made, then simple Pearson's correlations of variables were calculated for various sample subsets to suggest further interpretive analysis. Metal concentrations and other variables were displayed as a function of several master variables (pH, SC, depth). Several multivariate models to predict metal solubility or metal partioning also were constructed.

Suction lysimeter data were compared to soil chemistry analyses, ground-water quality, soil water content (neutron), and soil water potential (tensiometer) data to construct a model of metal transport in the vadose zone. Temporal and depth changes in metal levels also were compared.

Soil water content was compared between dates of measurement, and differences were interpreted by comparison to available meteorologic data. Spatial differences in soil water movement were noted also. Differences in soil water content with depth were related to soil texture differences observed during access tube installation. Soil water potential data obtained from tensiometers were used to infer direction and rate of soil water movement and to suggest where steady-state flow may be occurring.

A climate-based hydrologic model was used to simulate long-term water flow in tailings. Data collected during this RI investigation were used to partially calibrate the model.

Analyses of material samples obtained during Phase II monitoring well installation were compared to background geochemical levels to identify potential contaminant sources to the ground-water system.

DRAFT

3.0 DATA ANALYSIS AND INTERPRETATION

Both historic and RI-generated data were reviewed, analyzed, and interpreted for this report. Emphasis was placed on the RI data for interpretations, and historic data were used mainly for comparisons. This chapter is organized into a description of the hydrogeologic system, sources and transport of contaminants to Silver Bow Creek, and the effects of influent ground water on surface-water quality found during the RI. Historic data are included where appropriate. The Warm Springs Ponds area is not covered in this report, but is dicussed in detail in the Warm Springs Ponds Investigation Report, Appendix C.

Historic ground-water data are included as Attachment I, while RI data collected for this evaluation are included in Attachment VI. Prior to any discussion, the quality of the RI analytical data must be examined. Quality Assurance/Quality Control (QA/QC) data generated by the laboratory for both laboratory and field duplicates were included with each lab report and are compiled, averaged, and presented in Table 3-1. Absolute values of percent deviation were used in calculating the average percent deviation. Precision is important when comparing data points within any one study; accuracy is important when comparing data from different studies. Since only RI-generated analytical data were used in this evaluation, precisions are most important and are presented in the table.

TABLE 3-1
SBC RI GROUND WATER QA/QC SUMMARY

Parmeter Measured[a]	Average Lab Replicate Precision (± %)	Average Field Duplicate Precision (± %)
Cu (D)	1.9	2.5
Zn (D)	2.4	7.3
Fe (D)	3.1	6.0
As (D)	1.7	2.4
Pb (D)	2.1	5.4
Cd (D)	2.9	4.1
Ca	3.2	3.2
Mg	2.5	3.3
Na	2.2	2.4
K	3.0	3.8
Sulfate	2.2	5.7
Alkalinity	1.0	1.5
Cl	1.9	2.1
F	2.9	—[b]

Note:
(a) D = dissolved
(b) Not enough field duplicates to calculate

QA/QC results show the RI data to be very precise (reproducible). With this data quality information, RI data can be interpreted within a known confidence interval. Differences less than that confidence interval were considered insignificant unless the observation was consistent.

The data collected for this RI represented conditions during the period December 1984 through January 1986. This period was drier than average for Butte and may not be completely representative of typical conditions on Silver Bow Creek. Table 3-2 presents

TABLE 3-2
PRECIPITATION DATA FROM BUTTE, MONTANA
(in inches)

MONTH	AVERAGE[a] PRECIPITATION	RI STUDY PERIOD PRECIPITATION[b]	DEPARTURE FROM AVERAGE	PERCENT(%)
November 1984	.49	.62	+.13	+27
December	.48	.26	-.22	-46
January 1985	.42	.17	-.25	-60
February	.44	.34	-.10	-23
March	.65	.69	+.04	+ 6
April	.90	.18	-.72	-80
May	1.74	1.66	-.08	-5
June	2.42	1.22	-1.20	-50
July	1.20	.33	-.87	-73
August	1.03	1.52	+.49	+48
September	1.04	1.68	+.64	+62
October	.67	.76	+.09	+13
November	.49	.64	+.15	+31
December	.48	.21	-.27	-56
January 1986	.42	.28	-.14	-33
TOTALS	12.87	10.56	-2.31	-18

Note:

(a) Averages for the period 1931 to 1960 (National Oceanic and Atmospheric Administration 1971)

(b) National Oceanic and Atmospheric Administration 1985

monthly precipitation data for the RI study period and compares them to averages for the Butte area. Precipitation was particularly low for January, April, July, and December, but was higher than average for August through November. Overall, precipitation was 18% less than average during the RI study period.

Mountain snowpack is also important to the behavior of the Silver Bow Creek ground-water system. Table 3-3 lists the water content of the 1985 and 1986 snowpack as a percent of average. The table shows that early 1985 had greater than average water content in the snowpack, but an early melt and extremely low precipitation in April reduced water content to well below average. Early 1986 had much lower than average water content due to below average precipitation.

TABLE 3-3
SNOWPACK WATER CONTENT DATA FROM AROUND BUTTE, MONTANA
(Percent Of Average Water Content 1961-1980)(a)

Measurement Date	Basin Creek Station	Pipestone Pass Station	Moulton Reservoir Station
Jan. 1, 1985	137	122	113
Feb. 1	117	87	131
Mar. 1	107	105	87
Apr. 1	112	95	116
May 1	82	83	0
May 15	56	--	--
Jan. 1, 1986	76	87	32
Feb. 1	65	58	50

Note:

(a) USDA Soil Conservation Service, 1985 and 1986.

Below average precipitation, snowpack, and resultant streamflows provided an excellent opportunity to study the effects of ground-water inflows to Silver Bow Creek, because surface-related effects were subdued (Appendix A, Surface Water and Point Source report).

Although precipitation for 1985 was below average, it was a typical year. Years that are as dry as 1985 are well within one standard deviation of the average. This means drier years, like 1985, are quite common in the Butte area.

Additionally, the RI data represents a unique set of data, in that the Weed Concentrator was not discharging to Silver Bow Creek. The data collected during the RI therefore represent the lasting effects of past mining in the Summit Valley and not current operating conditions.

3.1 HYDROGEOLOGIC SYSTEM

This section describes several aquifer characteristics affecting the alluvial ground-water system present in the SBC RI study area: subsurface lithology and geology, ground-water flow directions and gradients derived from ground-water levels, vertical and lateral transmissivities as determined by aquifer testing, and general ground-water type(s). Raw and summarized data pertaining to these discussions are located in Attachments V and VI.

3.1.1 Lithology and Geology

Lithologic and geologic units vary considerably over the study area, and geologic structures control the thickness of the overlying unconsolidated material. The area's generalized geology is presented in Map 3-1, which summarizes major units and structures in the study area. The following discussion is divided into areas of similar geologic and lithologic characteristics, presented in down-stream order.

3.1.1.1 MSD Area

The lithology of the Butte Metro Storm Drain (MSD) area is characterized by thick deposits of unconsolidated Tertiary valley fill consisting of sand and gravel sequences with relatively thin, fine-grained lenses. Figure 3-1 is a longitudinal profile of the area's lithology, primarily based on materials found during drilling at wells GS-07, GS-08, and GS-13B, and supplemented by historic well logs. Specific sequences of strata within the unconsolidated material do not appear to be laterally continous or directly correlated. A Quaternary alluvial unit associated with the historic Silver Bow Creek channel is present, though distinguishing this unit from underlying Tertiary valley fill deposits is nearly impossible. The area is underlain by quartz monzonite at a depth of over 180 feet (well GS-07). Approximately 7 feet of buried tailings materials were encountered in Well GS-07 and GS-10, near the City-County Shop complex (Map 1-2 Over Size). Historic maps of the

LEGEND

- QUATERNARY ALLUVIUM
- QUATERNARY GLACIAL
- TERTIARY COLLUVIAL VALLEY FILL
- TERTIARY VOLCANIC
- CRETACEOUS INTRUSIVES

D / U UPTHROWN BLOCK

Note: Fault dashed where inferred, dotted where projected.

SCALE: 1" = 2 MILES

OPPORTUNITY

Match Line

Fig. 2 - Sh. 2

I-90 WEST

SILVER BOW CREEK

GREGSON

RAMSAY

U

D

ROCKER

WASTE DUMPS

BERKELEY PIT

I-15

BUTTE

SILVER BOW

I-15 SOUTH

ROCKER FAULT

BLACKTAIL CR.

I-90

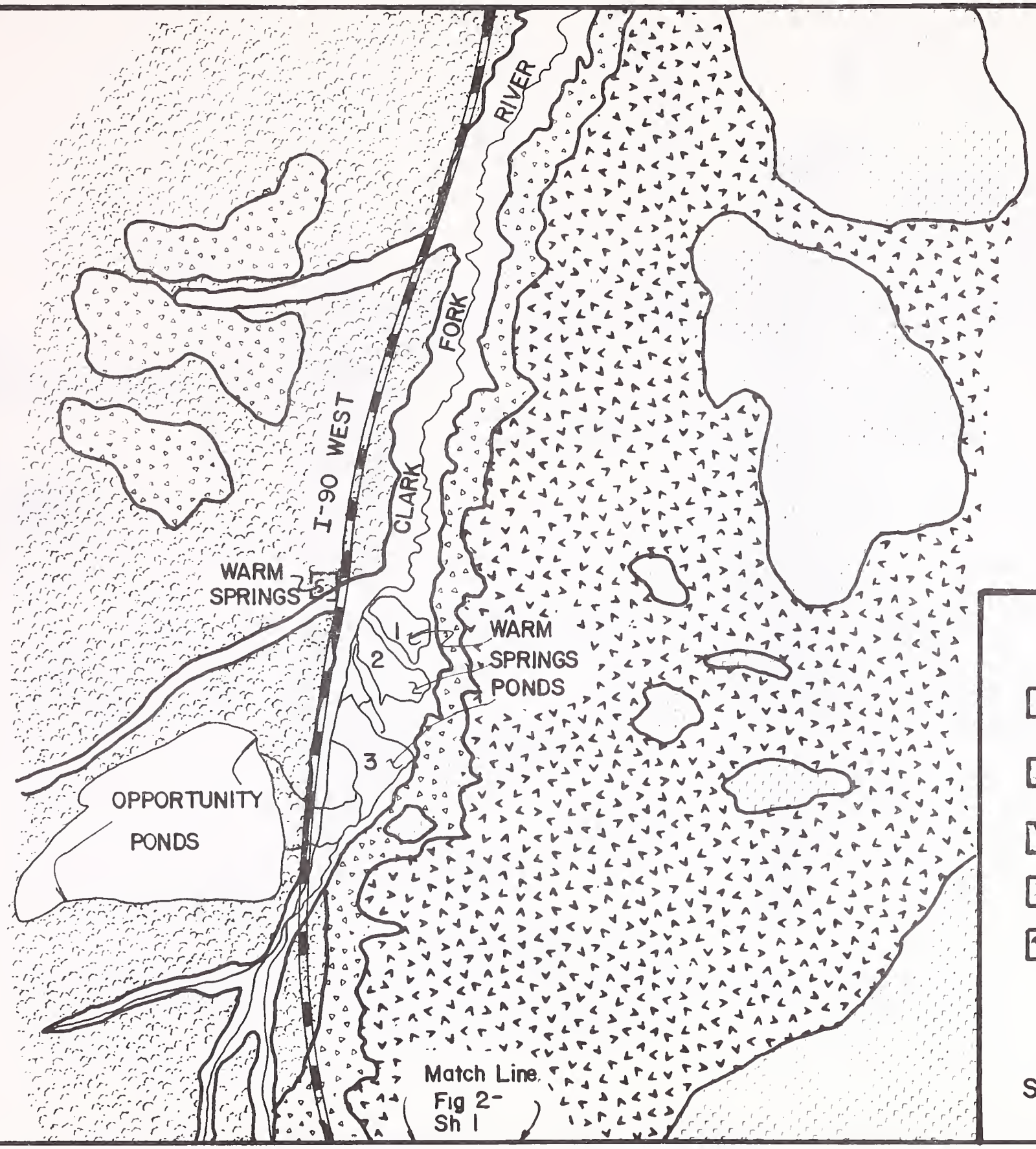
MAP 3-1

GENERALIZED GEOLOGIC MAP OF THE SILVER BOW CREEK REMEDIAL INVESTIGATION STUDY AREA; MODIFIED FROM SMEDES (1962 & 1968)

SHEET 1

MAP 3-1

GENERALIZED GEOLOGIC MAP OF THE SILVER BOW CREEK REMEDIAL INVESTIGATION STUDY AREA; MODIFIED FROM SMEDES (1962 & 1968)
SHEET 2



LEGEND

- QUATERNARY ALLUVIUM
- QUATERNARY GLACIAL
- TERTIARY COLLUVIUM VALLEY FILL
- TERTIARY VOLCANICS
- CRETACEOUS INTRUSIVES

SCALE: 1" = 2 MILES

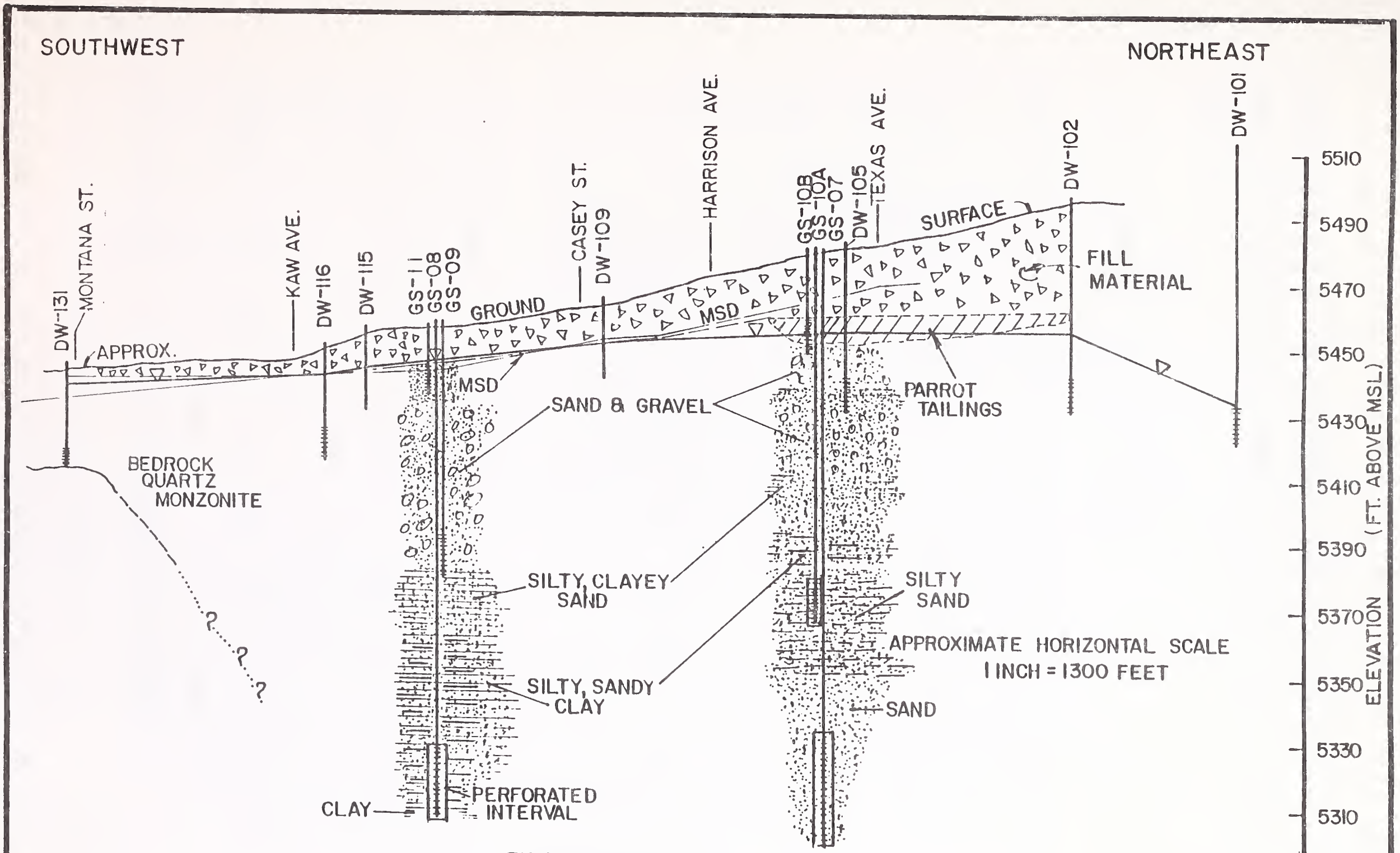


FIGURE 3-1

GENERALIZED PROFILE OF LITHOLOGY IN THE MSD AREA
SILVER BOW CREEK RI

Butte area (Weed 1897) indicate these tailings are located on or near the historic Parrot Smelter tailings pond on Silver Bow Creek (Map 3-2).

3.1.1.2 Montana Street to Rocker

The area between Montana Street and Rocker is quite different than that in the MSD area. A suspected geologic structure (probably a fault) located near Montana Street has raised bedrock to within 30 or 40 feet of ground surface in that area. Figure 3-2 shows the cross-sections from Map 3-3. The upthrown block (Map 3-1) is likely between Montana Street and the Rocker Fault near Rocker. Depth to bedrock west of the Rocker Fault is 100 feet or more below ground surface. The lithology consists of thin deposits of sand and silt overlying a relatively consistent zone of well-sorted gravel. The underlying bedrock consists of quartz monzonite and Tertiary volcanics.

Tailings deposits of thicknesses varying from less than one foot to a few feet are present throughout the floodplain between Montana Street and Rocker. Streamside tailings, the Colorado Tailings, and buried Butte Reduction Works tailings ponds are located here (Map 3-3). Manganese slagwalls have affected natural hydrologic processes between Montana Street and the Colorado Tailings by artificially controlling Silver Bow Creek surface flow, and they indirectly impact the area's ground-water system.

△ GS-14 Monitoring Well No.

BERKELEY PIT

0 1150' 2300'

Continental Drive

DW-101

TAILINGS

Weed Concentrator

PARROT TAILINGS

Civic Center Road

DW-102

DW-103

GS-07

GS-10A

DW-105

DW-108

GS-10B

Drain

DW-106

Front Street

DW-110

DW-109

DW-115

DW-107

Storm

DW-117

DW-116

DW-114

Main

Metra

George St.

DW-121

DW-131

DW-111

DW-113

DW-112

Harrison Avenue

Blacktail Avenue

GS-14

GS-08

GS-09

GS-11

DW-118

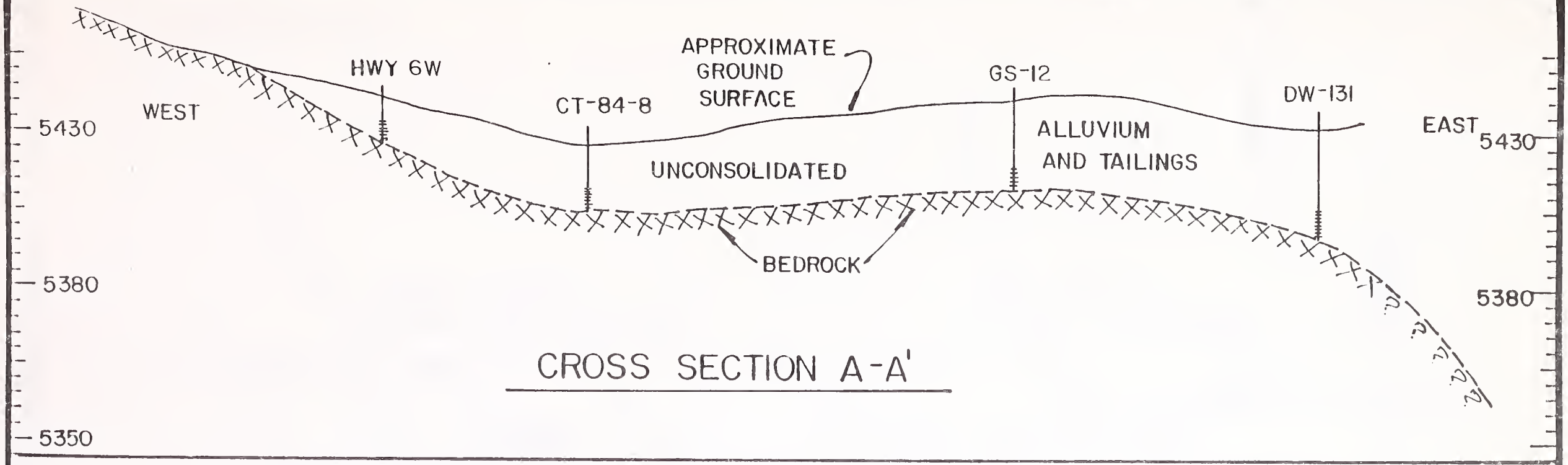
DW-119

Montana

Creek

MAP 3-2

LOCATION OF BURIED TAILINGS
IN THE MSD AREA



CROSS SECTION A-A'

CROSS SECTION B-B'

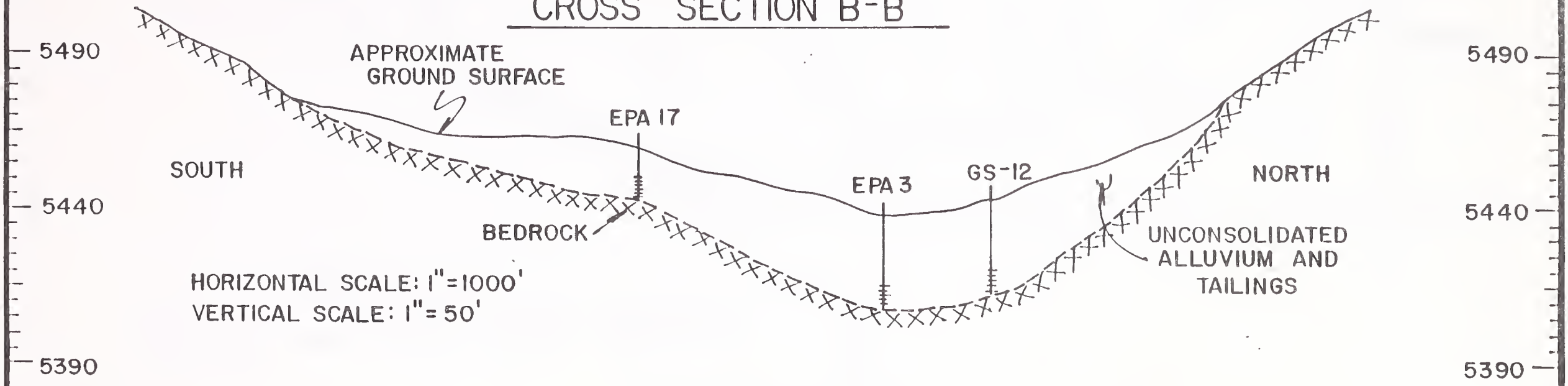


FIGURE 3-2

GENERALIZED CROSS SECTIONS DEPICTING DEPTH TO BEDROCK IN UPPER SILVER BOW CREEK FROM MAP 3-3

△ MONITORING WELL

COLORADO TAILINGS
(PRE-SBC CHANNELIZATION)

APPROX. EXTENT OF UNCONSOLIDATED MATERIAL

APPROX. A EXTENT OF UNCONSOLIDATED MATERIAL

B

B'

A

A'

Missoula Avenue

Centennial Street

Silver Bow Creek

Colorado Tailings

Gulch

Bow

BUTTE
REDUCTION WORKS
TAILING PONDS

Montana

Interstate 90

0 1000' 2000'

MAP 3-3

LOCATION OF COLORADO TAILINGS AND BUTTE REDUCTION WORKS TAILING PONDS: SILVER BOW CREEK RI;

3.1.1.3 Rocker to Silver Bow

Near Rocker, the Rocker fault forms the eastern margin of lacustrine and colluvial deposits which overlie the down-faulted Butte quartz monzonite (Proffett 1973) (Map 3-1).

Lithologies encountered during installation of wells GS-01 and GS-02 consisted of about 2 feet of tailings material overlying a thin, organic-rich peat zone. A relatively thick (12 to 15 feet) sand and gravel sequence underlies the peat to a depth of about 20 feet, and is underlain by an indefinite thickness of fine-grained material. The shallow sand and gravel layer carries most of the alluvial ground water in the area, while the subjacent fine-grained layer may provide a relatively impermeable base to the aquifer.

Bedrock units consist primarily of volcanics and quartz monzonite and apparently exert little influence on the ground-water system in the area.

3.1.1.4 Silver Bow to Miles Crossing

Between Silver Bow and Miles Crossing, colluvium and basin-fill deposits are at least 300 feet thick (according to logs of industrial wells constructed near Stauffer Chemical Plant), and are over 1000 feet thick in the Sand Creek area south of Silver Bow Siding (Noble et al. 1982). This sequence of unconsolidated, stratified material apparently contains numerous fine-grained layers and lenses with

low hydraulic conductivity. Well drillers' logs indicate several sand zones are present in the area which yield significant quantities of water.

Ancient Silver Bow Creek apparently incised its channel into older basin-fill colluvium and lacustrine deposits as shown on maps by Smedes (1968). The creek has developed a more significant alluvial unit along its course west of Silver Bow.

Drilling completed during the SBC RI (wells GS-03, GS-04, GS-05, GS-06, TS-01, and TS-02) indicate the alluvial system between Silver Bow and Miles Crossing is comprised of 1 to 8 feet of tailings overlying a 12 to 20 foot thick sequence of sand and gravel containing occasional fine-grained lenses. A fine-grained unit composed of dark green to reddish-brown clay or claystone underlies the coarse-grained units. The thickness of this unit is unknown, but it is at least 15 feet. For purposes of the investigation, the base of the alluvial aquifer was considered to be the top of this fine-grained unit.

Adjacent bedrock is composed of Tertiary-age volcanics which outcrop to the north, west, and south (Map 3-1). Bedrock units in the vicinity are distant both laterally and vertically in relation to the study area, so little emphasis was placed on characterizing bedrock.

Surface deposits of tailings materials are prominent along the Silver Bow Creek floodplain in this area between Silver Bow and Miles Crossing. The most extensive tailings deposit in the area is located south and west of the town of Ramsay and is known locally as Ramsay Flats (Map 1-3 Over Size).

3.1.1.5 Miles Crossing to Fairmont Hot Springs

West of Miles Crossing, Silver Bow Creek enters a volanic bedrock canyon. The canyon extends to Fairmont Hot Springs, where it opens up to the Deer Lodge Valley. Very little alluvium and no colluvium are known to be present in the bedrock canyon. Silver Bow Creek flows through a high energy environment in this area, and in many reaches the stream flows directly on subjacent bedrock.

Bedrock consists of Tertiary Lowland Creek Volcanics and Late Cretaceous intrusive rock related to the Boulder Batholith. The canyon reach of Silver Bow Creek is composed primarily of volcanic lava flows and mudflows. Few tailings deposits are present within the canyon, but isolated deposits occur on point bars in this reach.

3.1.1.6 Deer Lodge Valley

The Deer Lodge Valley includes the area between Fairmont and the Warm Springs Ponds and the area north of the ponds to Deer Lodge. The lithology of the Deer Lodge Valley is dominated by alluvial and glaciofluvial sediments and older colluvium. South of the Warm

Springs Ponds the thickness of these deposits is reported as greater than 5000 feet (Noble et al. 1982).

The alluvium and colluvium are similiar to that found in the upper portion of the study area. Alluvium is generally limited to modern drainages with the underlying basin-fill thickest in the middle of the valley. Intermixed with recent alluvium are unconsolidated glaciofluvial and lacustrine deposits (Konizeski 1962). Glaciofluvial deposits are thickest near the western margin of the Deer Lodge Valley (Noble et al. 1982). Ground water apparently occurs in numerous zones throughout the vertical sequence of these unconsolidated materials.

The Flint Creek Range to the west is composed of sedimentary rocks ranging in age from Precambrian to early Tertiary with a core of Laramide-age granite rocks (Mutch 1961). The mountains to the east are composed mostly of Laramide-age granitic rocks and Cretaceous and early Tertiary extrusive rocks.

Stream-deposited tailings are present adjacent to Silver Bow Creek and the Clark Fork River throughout the area. These deposits are not as thick as those found in the upper part of the study area, but their lateral extent is much greater.

3.1.2 Ground Water Levels

Ground-water table elevations were measured periodically at domestic wells and several monitoring wells, and continously at a few monitoring wells. These data are contained in Attachment V. Water level data collected suggest most wells reacted seasonally during the RI, with highest water levels occurring during spring measurements and lowest elevations during winter measurements.

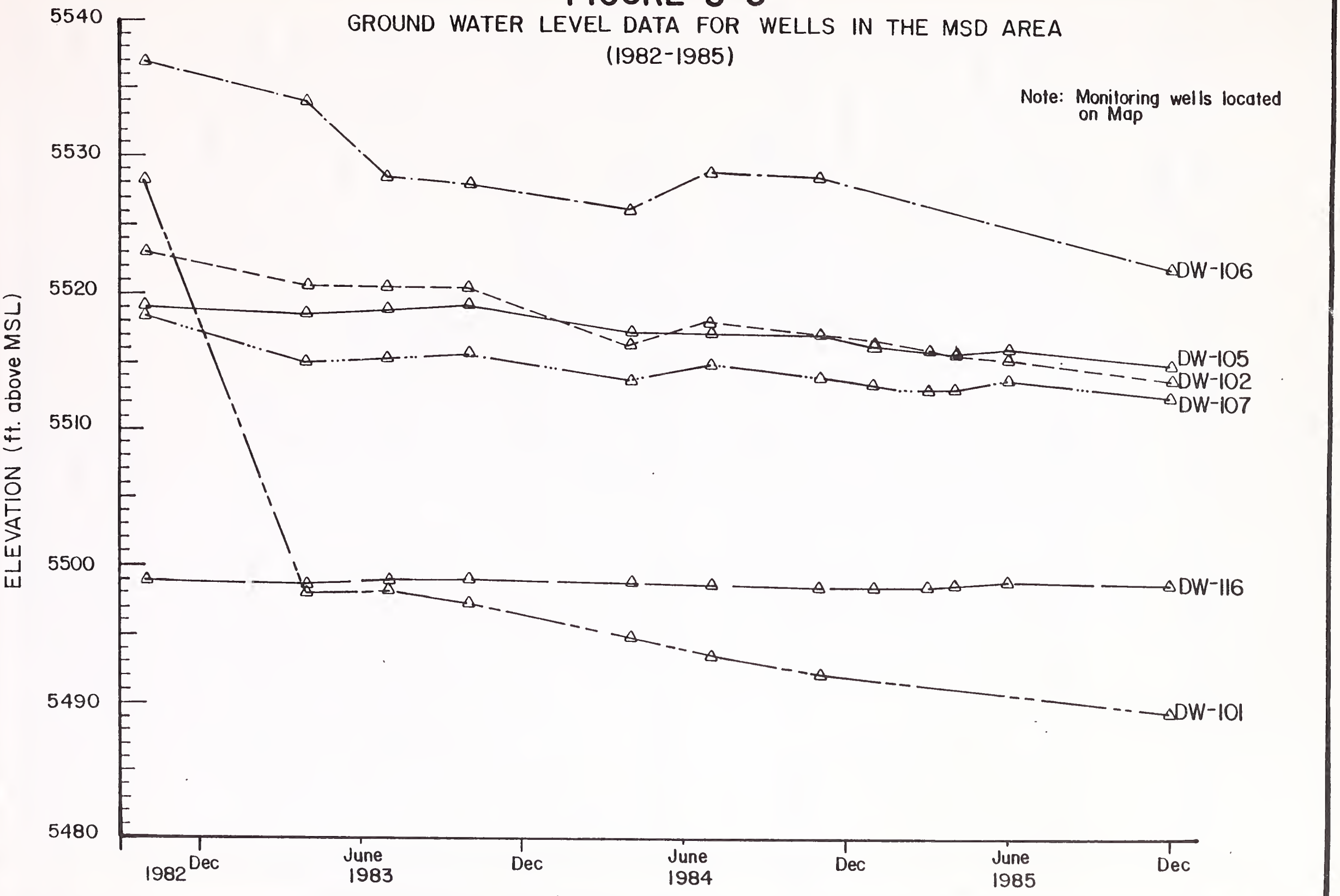
3.1.2.1 MSD Area

Analysis of historical water level data in the MSD area provides an insight to the effect of operational changes at AMC's Weed Concentrator. Figure 3-3 shows water level trends at several AMC monitoring wells since October 1982; locations of these wells are shown on Map 1-2 (Over Size) and Map 2-1. Most wells in the vicinity of the concentrator have experienced declining water level elevations since 1982. The magnitude of the observed water level decline is on the order of 8 to 12 feet, but a dramatic drop in water level (almost 30 feet) occurred in monitoring well DW-101 between October 1982 and April 1983. These water level declines coincide with cessation of discharges from the concentrator in February 1983. For comparison, water level elevations from monitoring well DW-116 are also plotted on Figure 3-3. This well is over one mile away from the concentrator and is not under the direct influence of the concentrator complex. Little variation in water levels appear in DW-116 over the period of record, indicating that water level

FIGURE 3-3

GROUND WATER LEVEL DATA FOR WELLS IN THE MSD AREA
(1982-1985)

Note: Monitoring wells located on Map



declines near the concentrator are probably not a function of climatic trends.

The best explanation for observed historical trends in water levels in this area is that the concentrator discharge to the MSD, and possibly process water contained on-site at the facility, exerted a significant influence on the local ground-water system in the form of ground-water mounding around the concentrator complex. Since the termination of concentrator operations, water levels in the area are dropping because of the flattening of the ground-water mound, recovering to its pre-impact elevation.

Figure 3-4 and Map 3-4 illustrate ground-water elevations in the MSD area, and indicate several important phenomena: (1) a ground-water divide is present in the unconsolidated Tertiary aquifer between Wells DW-105 and DW-102; (2) the ground-water table intercepts the base of the Parrot Tailings located near the upper end of the MSD; (3) the ground-water table intersects the base of the MSD near well DW-109; (4) a downward ground-water gradient is present near the upper end of the MSD in the vicinity of well GS-07; (5) recharge to the aquifer is from the east; and (6) ground-water movement is to the west in the eastern portion of the area and to the southwest along the MSD.

The ground-water divide located between wells DW-105 and DW-102 is due to the influence of the adjacent Berkeley Pit draining ground water from the unconsolidated material around it. The Berkeley Pit

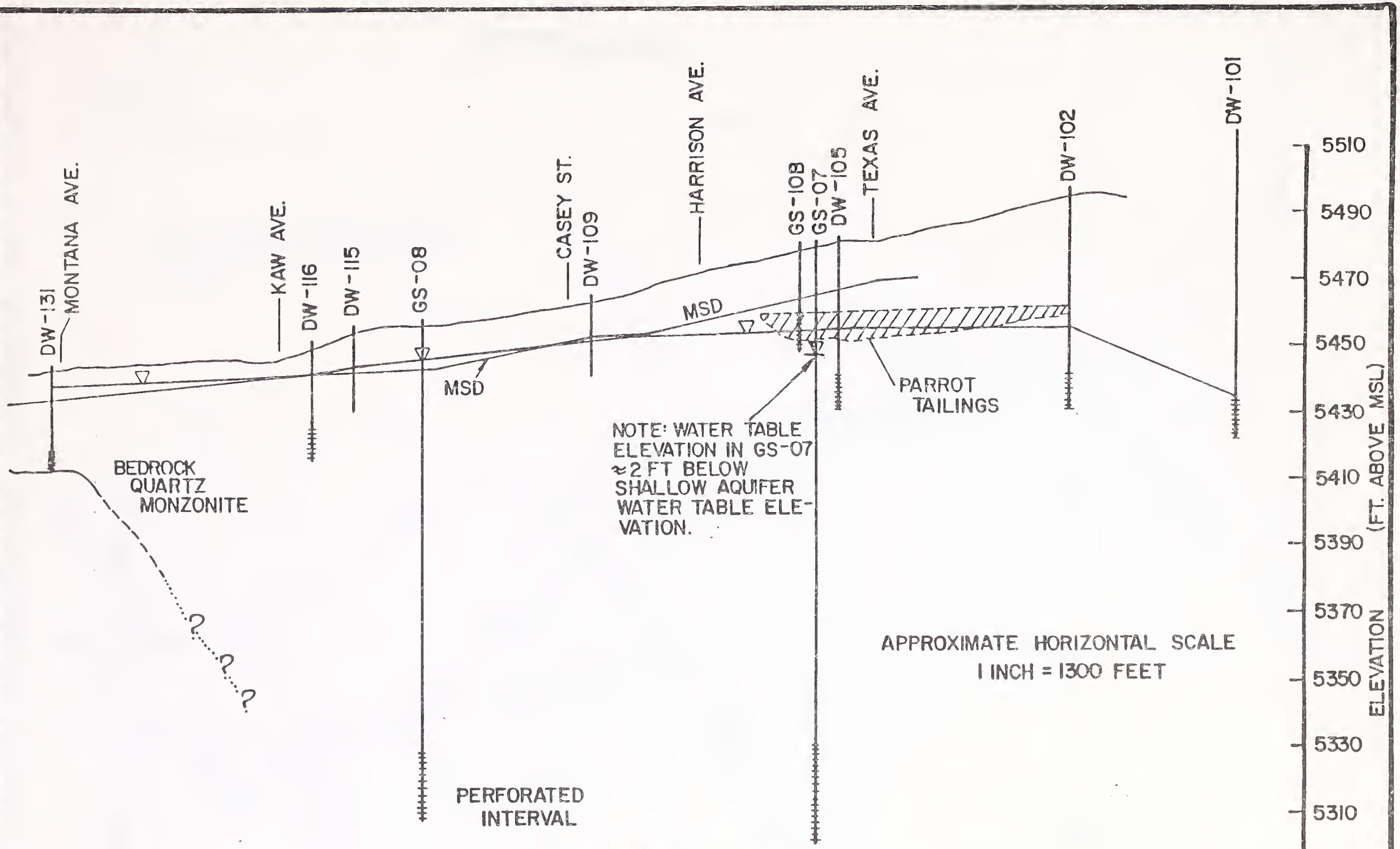
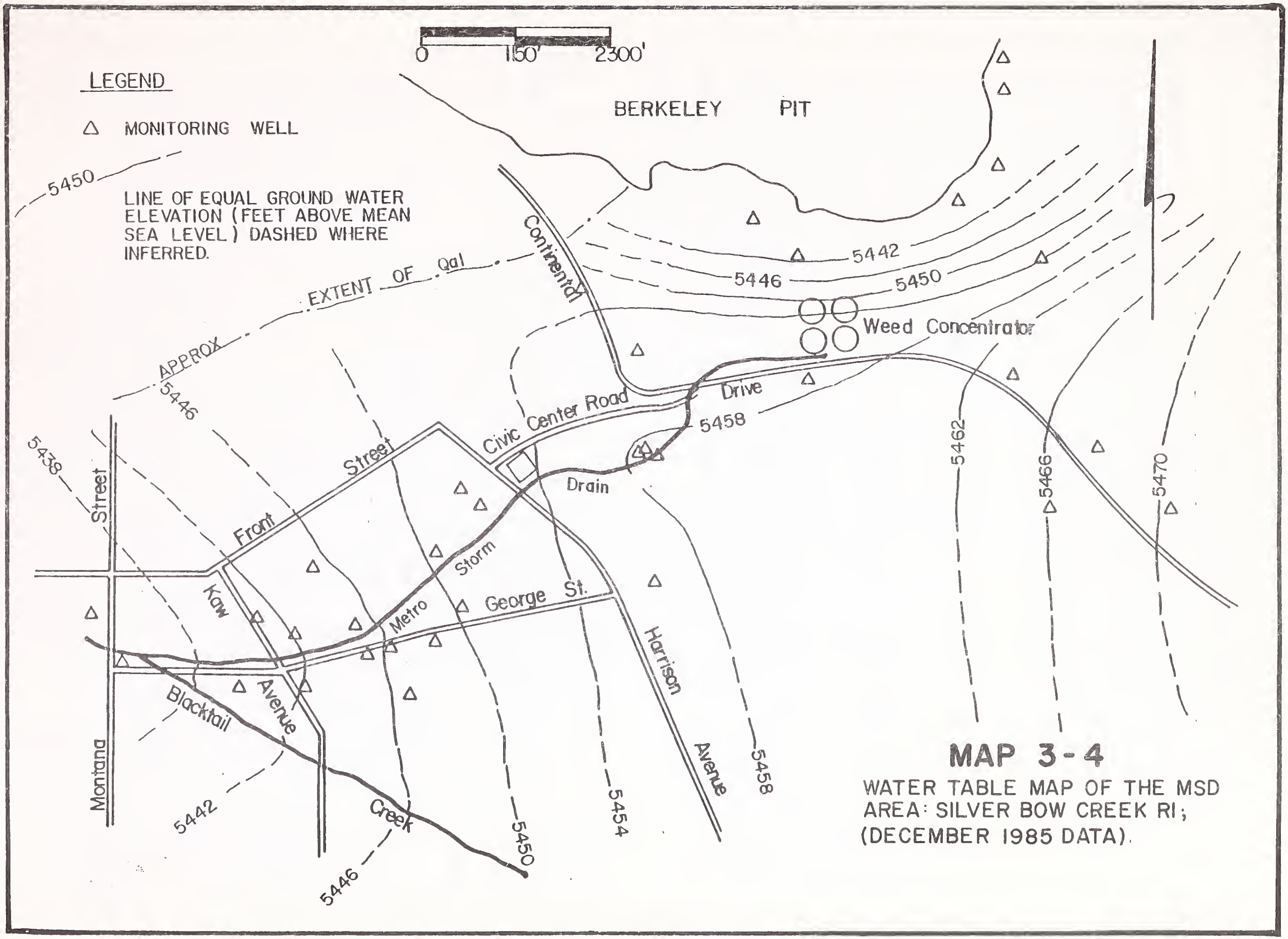


FIGURE 3-4

GENERALIZED LONGITUDINAL PROFILE OF MSD AREA
WATER TABLE: SILVER BOW CREEK RI; (DECEMBER 1985 DATA)



MAP 3-4

WATER TABLE MAP OF THE MSD AREA: SILVER BOW CREEK RI; (DECEMBER 1985 DATA).

probably will continue to maintain this ground-water divide until the unconsolidated material in the upper portion of the pit is resaturated by water level recovery within the pit and historic flow lines to the south and southwest are re-established.

A downward vertical hydraulic gradient is evident at well cluster GS-07 (Wells GS-07, GS-10A, and GS-10B), located near the upper end of the MSD (Map 1-2 Over Size and Map 2-1). The magnitude of the vertical gradient measured at this well cluster is approximately 3%. This compares to a lateral ground-water gradient of about 0.3% (Map 3-4). Water level data from the well cluster located midway down the MSD (Wells GS-08, GS-09, and GS-11) show no measurable vertical gradient.

Two explanations are possible for the downward vertical gradient observed near the upper MSD. The downward gradient may be a remnant from historic recharge provided by the Weed Concentrator, or it may be a result of dewatering the underlying bedrock by historic pumping of ground water around the Berkeley Pit. Water levels in bedrock are represented by data collected from the nearby Belmont mine shaft, which had a water level nearly 900 feet below ground surface in December 1985 (Montana Department of State Lands' files). An unsaturated zone appears to be present between the base of the unconsolidated material aquifer and the top of the recovering bedrock water table, which would cause gravity drainage of the overlying unconsolidated material aquifer and explain the observed downward vertical ground-water gradient. Vertical head differences

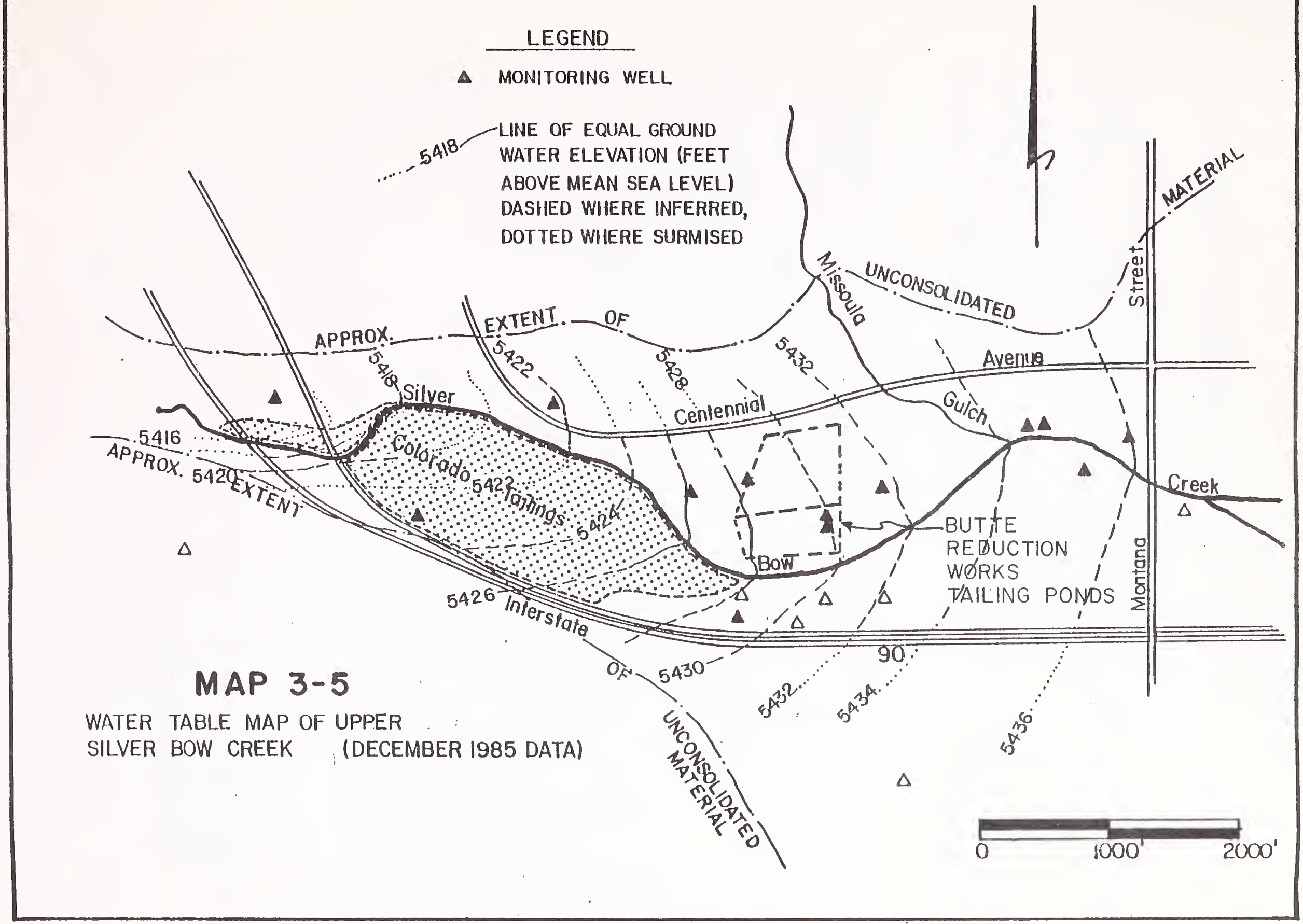
were not observed at the GS-08 well cluster because the underlying bedrock is probably saturated. The extent of the influence of the Berkeley Pit on the bedrock aquifer is somewhere between well clusters GS-07 and GS-08 (Map 1-2 Over Size).

3.1.2.2 Upper Silver Bow Creek

Ground-water level data from nested monitoring wells in the area between Montana Street and the Colorado Tailings indicated no measurable variability in hydraulic head with depth in the alluvial aquifer. However, underlying bedrock becomes abruptly shallower from east to west (Figure 3-2) and this may force some ground water upward into shallower portions of the alluvial aquifer and into Silver Bow Creek.

Map 3-5 is a potentiometric map of the alluvial aquifer in upper Silver Bow Creek. The ground-water gradient is generally to the west at about 0.2%. A component of ground water appears to enter the Silver Bow Creek alluvial system from the southeast and is associated with the Blacktail Creek alluvial system.

Ground-water levels in the area of the historic Butte Reduction Works tailing impoundments (Map 3-5) are relatively shallow, on the order of 3 feet below ground surface. Although the thickness of the tailings in the area is unknown, at least a portion of these tailings are likely to remain saturated throughout the year.



MAP 3-5

WATER TABLE MAP OF UPPER SILVER BOW CREEK (DECEMBER 1985 DATA)

3.1.2.3 Rocker to Fairmont

Further downstream, continous records of water level fluctuations were obtained at monitoring wells GS-01, GS-02, GS-03, GS-04, TS-01, and TS-02 (Map 1-3 Over Size). Monitoring wells GS-03 and GS-04 were installed at different depths in Silver Bow Creek alluvium adjacent to the creek to document the effect of bank storage.

Data suggest a direct relationship between changes in stream stage and ground-water levels in the shallow alluvial system. Examples of this relationship include a snowmelt event on the creek in early April, a precipitation event during early June, and diurnal fluctuations in ground-water levels between March and August. Bank storage is prominent in the alluvial aquifer here. As stream stage rises, ground-water levels rise in response; when stream stage drops, a time lag occurs before ground-water levels decline to their former level. This phenomenon was most evident in early June 1985 following a significant precipitation event and associated stream stage rise (see Appendix A, Surface Water and Point Source report). Silver Bow Creek recovered to its pre-storm stage within four days, while it took at least ten days, for ground-water levels to return to pre-storm levels.

Continuous ground-water level data from monitoring well TS-01, located near the center of Ramsay Flats, exhibits fluctuations similar to those recorded at wells next to Silver Bow Creek, although of much less magnitude. Diurnal fluctuations are evident during

late spring and summer months, and the well responded to a significant precipitation event in early June, but its reaction was several hours later than other near-stream wells and stage rises in Silver Bow Creek. This lag is indicative of infiltration recharge to the alluvial aquifer.

Monitoring well TS-02 was installed to document water level characteristics in Ramsay Flat tailings, but because the tailings were not saturated during 1985, continuous water level data from this monitoring well are inconclusive. Tailings saturation on Ramsay Flats was documented by Hydrometrics (1983a) during spring 1982.

3.1.2.4 Deer Lodge Valley

Few data exist for the rest of the study area. In the southern Deer Lodge Valley, Konizeski et al (1968) suggest ground-water movement is to the north, changing to northeast in response to the Mill and Willow Creeks ground-water systems entering from the west. Further north, ground-water levels in the floodplain area of the Clark Fork River are usually less than 10 feet below ground surface, while adjacent alluvial fans and terraces have depths to ground water ranging from 10 to 150 feet. Maps show ground-water movement is generally to the northeast along the west side of the Clark Fork River and to the northwest on the east side of the river (Konizeski et al. 1968).

Water-level data collected during the RI in the Deer Lodge Valley were insufficient for spatial or temporal trend analysis. Data indicate depth to water ranged from about 18 to 21 feet below the ground surface for wells measured. Measured wells were typically located on the first or second terraces above the floodplain. The data south of the Warm Springs Ponds suggest water levels dropped measurably from early to mid-1985.

3.1.3 Transmissivity

Both historic (Jacob 1963) and RI aquifer tests were analyzed to estimate ranges of transmissivity values for the alluvial aquifer. These data are discussed below and referenced, and RI data are presented in Attachment V. Although both drawdown and recovery tests were performed, only the drawdown data were meaningful. Recovery data generally did not produce plots that could be meaningfully evaluated, since the aquifers tested recovered too quickly to allow accurate measurement in the field. Transmissivity values obtained from drawdown in the pumped well are not as reliable as transmissivity values calculated from drawdown and recovery data from observation wells finished in the same zone as the pumped well. Additionally, short term tests have some limitations with respect to hydraulic conductivity calculations. The values used in this report are estimates based on the best data available.

3.1.3.1 MSD Area

Aquifer tests were performed in the MSD area at monitoring wells GS-07, GS-08, and GS-09 (Map 1-2 Over Size and Map 2-1). Both constant-discharge/drawdown and recovery tests were performed at the three monitoring wells.

Monitoring well GS-07, located near the upper end of the MSD, was pumped for five hours at about 20.5 gallons per minute (gpm), with an observed maximum drawdown of 113 feet. Hydraulic conductivity at GS-07 was calculated as 10 gpd/ft^2. Observation wells GS-10A and GS-10B were located approximately 10 feet from the pumped well: well GS-10B did not react significantly during the drawdown test of GS-07, but a drawdown of 0.4 feet was measured in well GS-10A. Well GS-10A is completed approximately 25 feet shallower than GS-07, and the reaction of well GS-10A during such a short test indicates that vertical interaction probably occurs within the ground-water system, at least locally.

Other short-duration aquifer tests were performed at monitoring wells GS-08 and GS-09, similar to that completed at GS-07. Calculated hydraulic conductivities, based on drawdown data, ranged from 17 gpd/ft^2 at GS-08 to 29 gpd/ft^2 at GS-09. Aquifer permeability appears greater at shallower depths, at least locally. During the drawdown test at GS-09, adjacent monitoring wells less than 15 feet away and completed at different depth intervals, showed no significant response. During the pumping test of deeper well GS-08, a

slight but measurable drawdown occurred in the two shallow observation wells, GS-09 and GS-11. This drawdown may indicate some vertical interconnection within the ground-water system, given the short duration of the aquifer test.

Ground-water movement in the MSD area is likely inhibited by the relatively low permeability, poorly-sorted material present in the area. Calculated hydraulic conductivities of the unconsolidated material aquifer are low (less than 30 gpd/ft^2). Some vertical variability appears to exist within the aquifer; more permeable material is apparently located at shallower depths, although no aquifer testing was performed on wells shallower than 60 feet. The higher permeabilities probably are caused by the more recent Silver Bow Creek alluvial gravels. This material is probably better-sorted and coarser than underlying units, and hence, more permeable.

Aquifer test data show slight reactions in water levels in shallower wells when adjacent deeper wells are pumped. This occurrence indicates that vertical interactions within the aquifer probably occur to some extent. Fine-grained zones identified within the unconsolidated material aquifer in the MSD area (Attachment III) apparently exert significant control on vertical ground-water movement. These fine-grained units probably act as aquitards, but the lateral extent of these units is unknown.

3.1.3.2 Upper Silver Bow Creek

In the Colorado Tailings area, historic data are available for transmissivities of the tailings and the underlying Silver Bow Creek alluvium. Hydrometrics (1983e) estimates transmissivity of the Colorado Tailings between 10 and 720 gpd/ft. Alluvial aquifer transmissivities beneath the Colorado Tailings are reported as 5000 gpd/ft (Intrasearch 1984 and MBMG 1985).

During the RI a constant discharge aquifer test was performed in this area at monitoring well GS-13B, and a bailer recovery test at monitoring well GS-15A (Map 1-2 Over Size and Map 2-2). Data from these tests indicate the alluvial aquifer here was very tight and exhibited hydraulic conductivities on the order of 20 gpd/ft^2. A degree of vertical connectedness was indicated. The reaction of shallow well GS-13A was approximately 0.2 feet when the adjacent pumped well (GS-13B) had a water level more than 22 feet below its static water level; monitoring well GS-13A is less than 20 feet from GS-13B. The fact that the shallow well reacted during the short-duration pumping test indicates vertical interaction occurs within the aquifer, at least locally.

3.1.3.3 Rocker to Fairmont

An aquifer test was performed west of Rocker at well GS-01, completed in Silver Bow Creek alluvium, using a constant discharge technique.

Adjacent monitoring well GS-02 was used as an observation well during pumping of well GS-01 (Map 1-3 Over Size).

The alluvial aquifer around GS-01 exhibits relatively low hydraulic conductivity values. Based on an assumed aquifer width of 100 feet and an aquifer gradient of 0.003, approximately 150 gallons per day moves through the Silver Bow Creek alluvial system in this area. Observation well GS-02 did not react measurably during pumping of well GS-01, even though the well is located only 8 feet away. Well GS-02 is completed in shallow, fine-grained material and the lack of response to adjacent pumping indicates little vertical hydraulic connection within the alluvial aquifer, at least locally.

Farther downstream, a four-hour constant discharge aquifer test was completed at monitoring well GS-03 near Silver Bow, and a 24-hour constant discharge test was performed at monitoring well TS-01, located on Ramsay Flats (Map 2-5). Both wells are completed in Silver Bow Creek alluvium.

Results of the aquifer tests show that hydraulic conductivity values were about 500-900 gpd/ft^2, an order of magnitude greater than those measured upstream near Rocker. Pumping of well GS-03 produced a measurable drawdown in adjacent well GS-04, completed in the shallower portion of the aquifer, which suggests the alluvial aquifer in this vicinity is hydraulically connected.

A more extensive and detailed aquifer test was performed at Ramsay Flats pumping well TS-01; observation wells TS-03 and TS-04 were sited west of TS-01, 15 feet and 40 feet, respectively. Observation well TS-05 was located 20 feet south of TS-01 and was sited to measure the degree of anisotropy in the alluvial aquifer. Locations of pumping and observation wells on Ramsay Flats are shown on Map 2-5. Observation wells TS-03 and TS-05 reacted quickly and dramatically as soon as the pump was started in pumping well TS-01. The observation wells also reacted to any perturbations in water levels in the pumping wells. A degree of anisotropy was measured by comparing water levels in TS-05 and TS-03: Drawdown at TS-05 was nearly 0.4 feet more than at TS-03, even though TS-05 was five feet further away from pumping well TS-01. This observation indicates greater permeabilities of unconsolidated sediments of Silver Bow Creek alluvium occur in an east-west orientation, at least locally, probably due to the historic Silver Bow Creek channel under the Ramsay Flats tailings.

Other shallow monitoring wells (TS-06, TS-07, TS-08) (Map 2-5) are located adjacent to TS-01 on Ramsay Flats. These wells were not monitored during the aquifer test because the wells were dry at the time of the test, and the hydraulic relationship of the tailings and the underlying alluvial system was not quantified.

3.1.3.4 Deer Lodge Valley

No aquifer tests were performed in the Deer Lodge Valley as part of the SBC RI, but Konizeski et al. (1968) reports aquifer test data for several wells in and adjacent to the study area.

Data from the area south of the Warm Springs Ponds indicate transmissivity values range from 15,000 to 95,000 gpd/ft. Specific capacities of wells tested ranged from 1 to over 15 gpm/ft. The wells were completed in Quaternary alluvium and/or underlying Tertiary unconsolidated material. The variability in hydraulic values were attributed to location in the valley with respect to recharge areas and well completion intervals. North of the Warm Springs Ponds, transmissivities in Clark Fork River alluvium ranged from 25,000 to 80,000 gpd/ft. Specific capacities of the wells tested ranged from 6 to 36 gpm/ft. The Clark Fork River alluvium is relatively thin and not laterally extensive; hence, yields from wells completed in the unit are limited to a few hundred gallons per minute.

Tertiary sediments exhibit much lower transmissivities than alluvial units but have a much greater saturated thickness. Transmissivity in the Tertiary sediments ranged from 600 to 70,000 gpd/ft. in five wells tested (Konizeski et al. 1968). Estimated specific capacities ranged from 1 to 40 gpm/ft; most were less than 10 gpm/ft.

3.1.4 Ground-Water Type

Ground water in the study area was characterized by analyzing for major cations (calcium, potassium, magnesium, sodium) and major anions (sulfate, chloride, and alkalinity--bicarbonate and carbonate). Stiff diagrams were prepared (included in Attachment VI) to show relationships between the major ions and indicate general aquifer chemistry. This procedure allowed the ground water to be classified and compared to other wells and other areas.

3.1.4.1 MSD Area

Stiff diagrams prepared for the MSD area showed that ground water is almost exclusively a calcium-sulfate type. The only exception is monitoring well DW-103, which has sodium/potassium-sulfate type water. This well is located upgradient of the MSD and the concentrator complex and probably represents background ground water in the area.

The magnitude of the calcium and sulfate components of the Stiff diagrams is variable between monitoring wells. Ground water in monitoring wells DW-101, DW-105, DW-109, DW-110, DW-116, DW-119, GS-07, GS-09, GS-10A, GS-11, and GS-14 all exhibit atypically high percentages of both calcium and sulfate. These wells are located adjacent to the MSD. The other wells are located laterally away from the MSD and have less skewed Stiff diagrams.

The deeper component of ground water in the unconsolidated material aquifer changes character significantly from upgradient to downgradient, which is typified by comparing Stiff diagrams for monitoring wells GS-07 and GS-08. The two wells are completed at about the same elevation and contain the same type of water. However, the magnitude of the calcium and sulfate components of the Stiff diagrams is much greater in upgradient well GS-07 than in downgradient well GS-08.

The Blacktail Creek alluvial system contains ground water significantly different and with much lower concentrations than that in the MSD area (Well DW-121). Monitoring wells located east of and upgradient from the MSD (DW-103 and DW-106) exhibit ground water dissimilar to that in the MSD area.

A trilinear diagram of monitoring wells in the MSD area is shown on Figure 3-5. The figure indicates monitoring wells DW-111, DW-115, and DW-121 group separately from other sampled wells. These wells contain significantly different water than the other wells, which is probably reflective of their distant location relative to degraded ground water in the MSD area. Monitoring wells DW-111 and DW-115 are located a distance away from the MSD and are probably on the periphery of the contaminated ground water. Monitoring well DW-121 is completed in the Blacktail Creek alluvium and, as described previously, contains significantly different water than those located in the vicinity of the MSD.

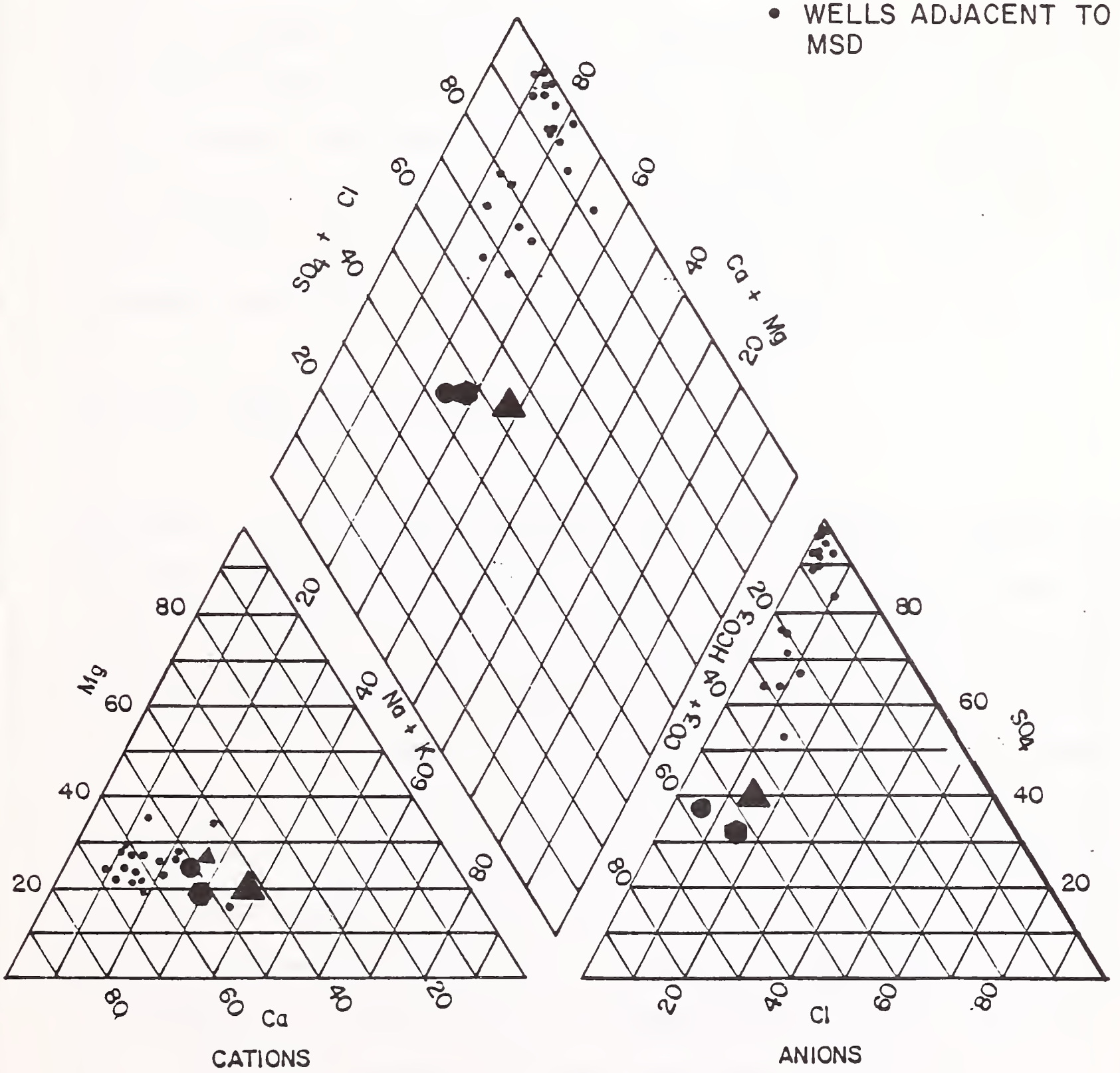


FIGURE 3-5

TRILINEAR DIAGRAM OF MONITORING WELLS IN MSD AREA (DECEMBER 1985 AND JANUARY 1986 DATA)

Figure 3-6 is a trilinear diagram which depicts the relationship between shallow monitoring wells (<20 feet) and deeper monitoring wells constructed during the RI in the MSD Area. The diagram shows little vertical variability in ground-water quality except for monitoring well GS-10B. This well is not representative of shallow ground water chemistry due to well completion problems. Well GS-10B exhibited anomalous water quality data because the sand pack placed about the perforated interval failed and allowed poor quality backfill material from above to enter the perforated zone.

3.1.4.2 Upper Silver Bow Creek

Analysis of the Stiff diagrams for the Montana Street-Colorado Tailings area indicates ground water is generally a calcium-sulfate type: exceptions include monitoring well DW-130, which exhibits sodium/potassium-sulfate type water; DW-123, which contains calcium-chloride type water; and DW-122, which has calcium-bicarbonate type water. Monitoring well DW-130 is located north of Centennial Avenue (Map 1-2 Over Size and Map 2-2) and possibly intercepted a component of ground water moving to the south, or is located away from contaminated ground water. Monitoring wells DW-123 and DW-122 are completed in ground water probably moving to the northwest from the vicinity of Montana Pole and Treatment Company from the Blacktail Creek alluvial system. Hence, the chemistry of ground water in these wells is unique from those completed in the Silver Bow Creek alluvial system in this area.

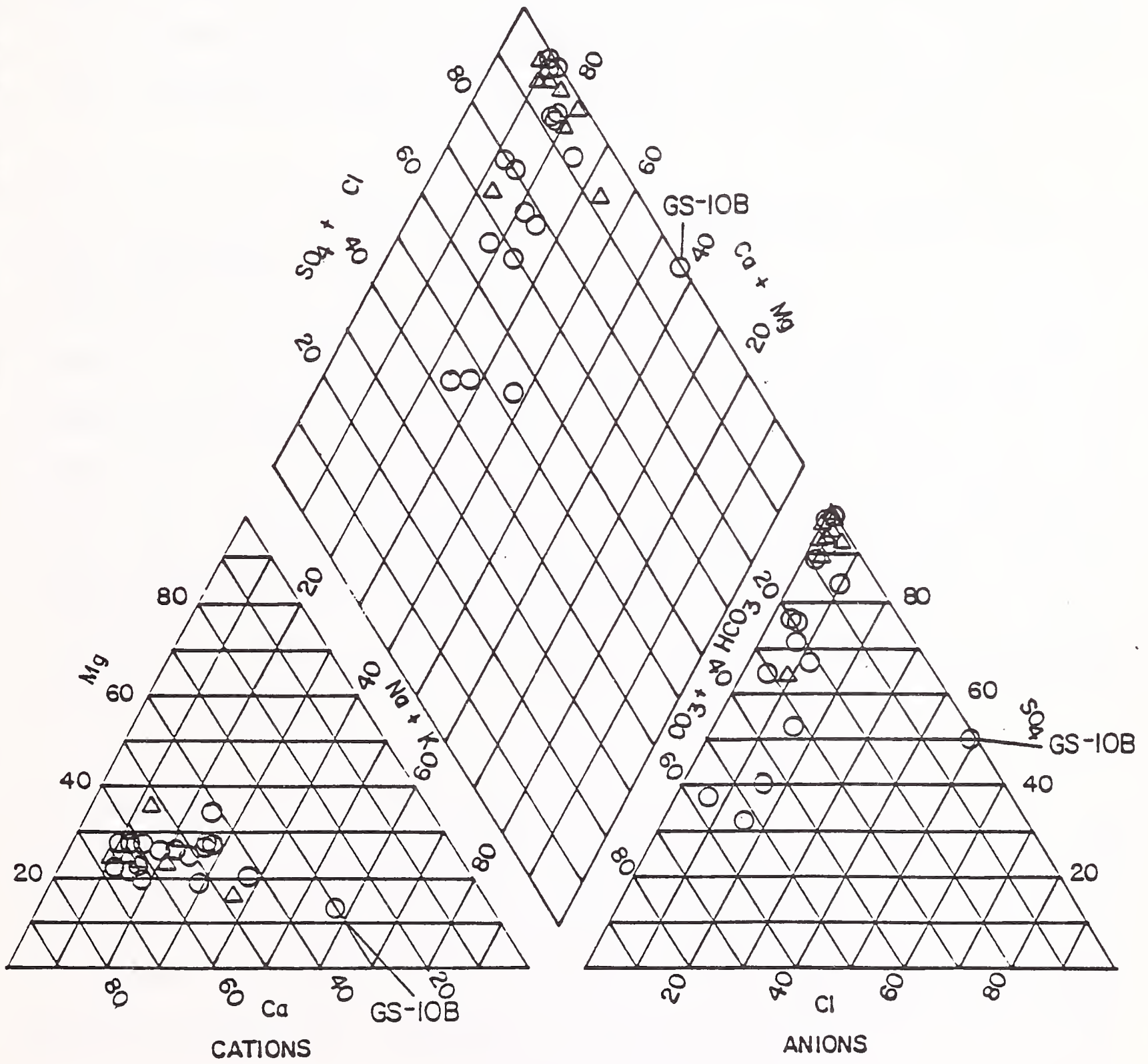


FIGURE 3-6

TRILINEAR DIAGRAM OF SHALLOW AND DEEP MONITORING WELLS IN MSD AREA: SILVER BOW CREEK RI; (DECEMBER 1985 AND JANUARY 1986 DATA)

Water quality characteristics evident in Stiff diagrams from monitoring wells DW-136 and DW-137 show significantly different concentration magnitudes from other monitoring wells in upper Silver Bow Creek. These two wells are located within the historic Butte Reduction Works tailings impoundments east of the Colorado Tailings and show distinctly higher sulfate relative to other wells.

The trilinear diagram (Figure 3-7) shows Wells DW-136 and DW-137 plot separately from others in the area. It also shows that monitoring wells completed north of Silver Bow Creek (e. g. DW-136, DW-137, DW-131, DW-132, GS-13A, and GS-13B) group separately from those installed south of Silver Bow Creek. This separation indicates lateral zonation of ground-water in this area, with Silver Bow Creek as the dividing line. Although the MSD and Blacktail Creek alluvial ground-water systems merge at this point, they apparently do not mix, and Silver Bow Creek may act as a hydraulic barrier to mixing.

A comparison of ground water in the MSD and upper Silver Bow Creek areas is presented on a trilinear diagram in Figure 3-8 and shows two different types of water. This difference is probably due to the influence of the Blacktail Creek alluvial ground-water system changing the character of the ground water in this area.

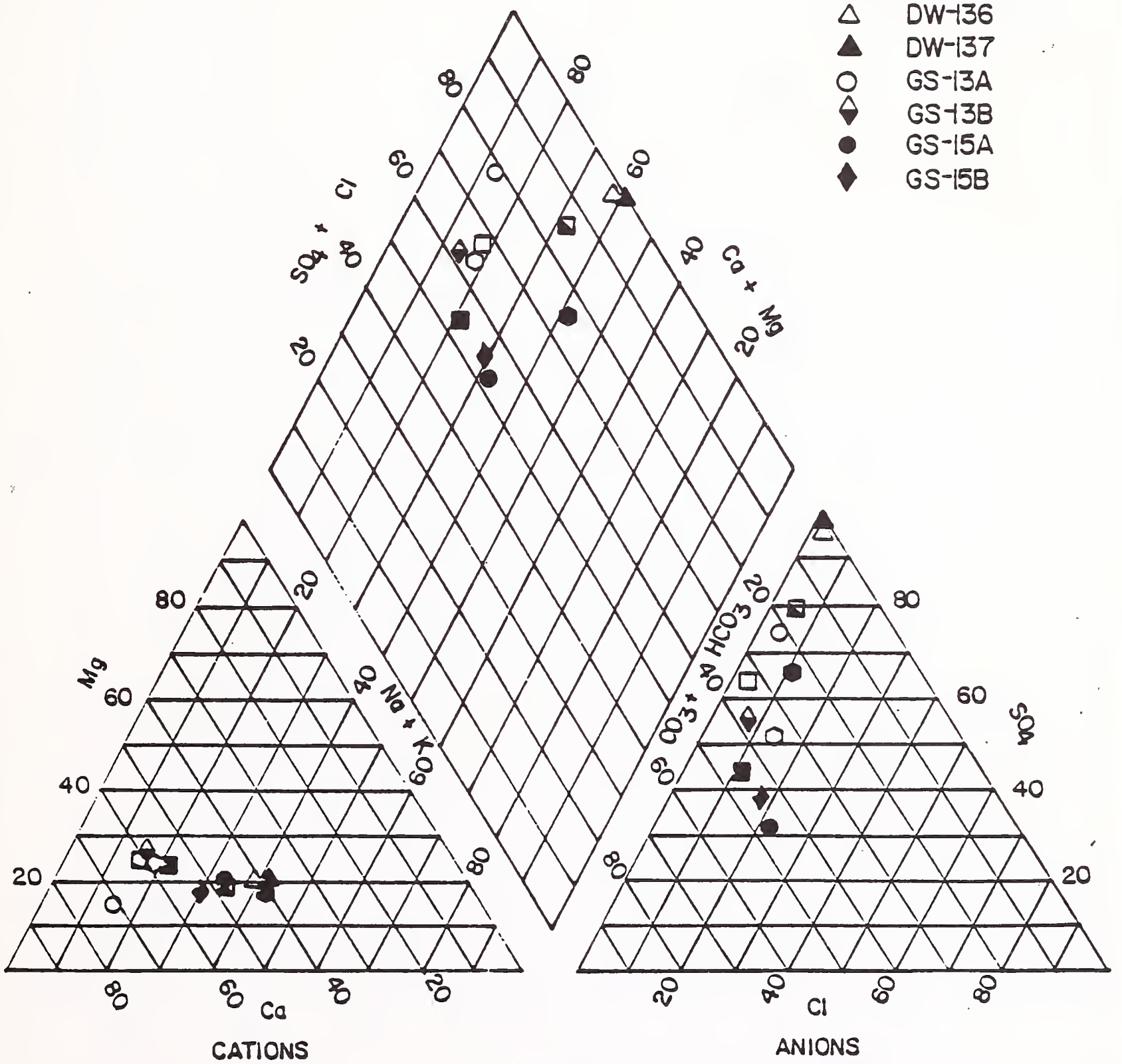


FIGURE 3-7

TRILINEAR DIAGRAM OF MONITORING WELLS IN UPPER SILVER BOW CREEK (DECEMBER 1985 DATA)

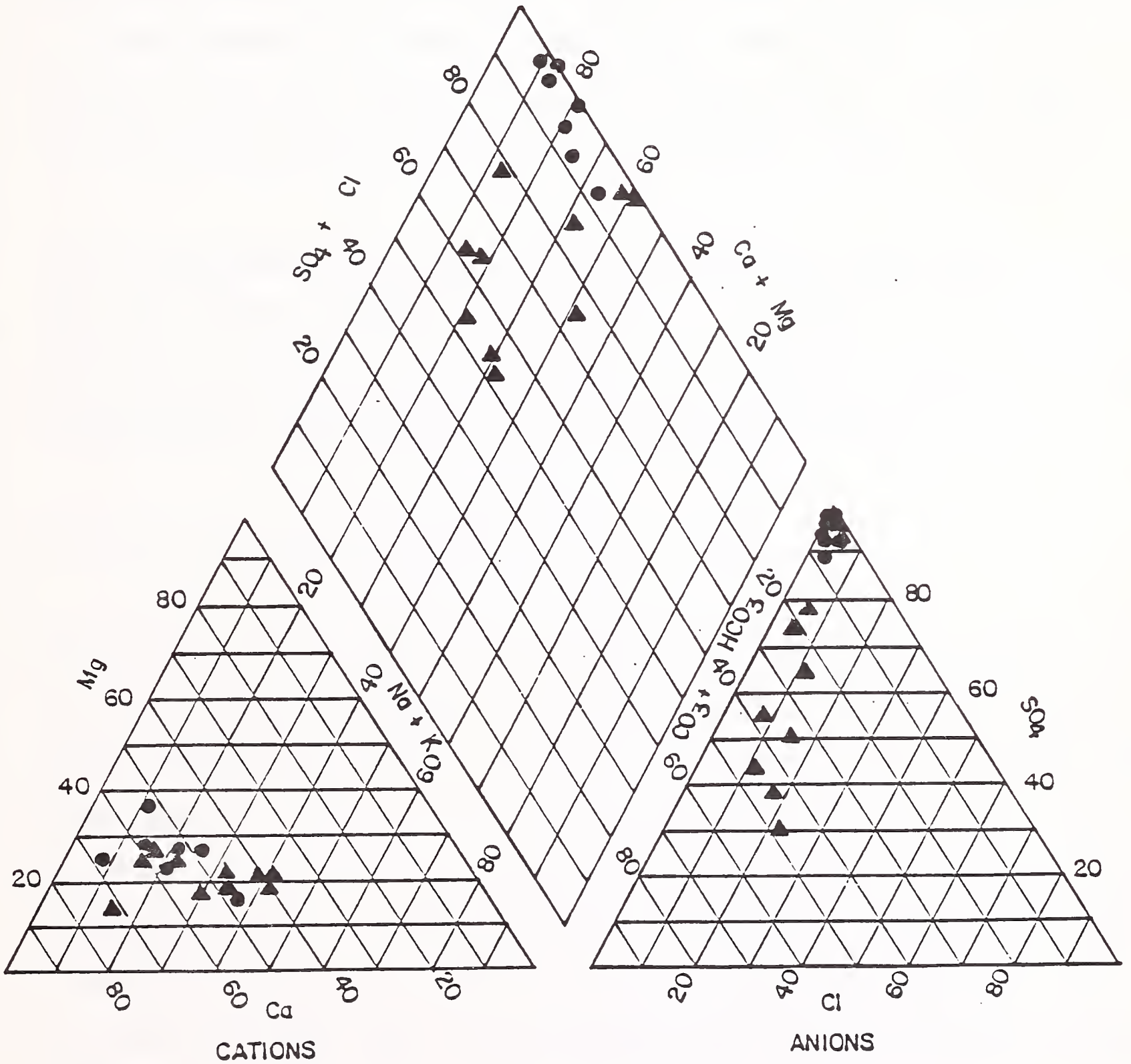


FIGURE 3-8

TRILINEAR DIAGRAM OF MONITORING WELLS IN THE MSD AND UPPER SILVER BOW CREEK AREAS SILVER BOW CREEK RI; (DECEMBER 1985 DATA)

3.1.4.3 Rocker to Fairmont

Ground water between Rocker and Silver Bow is generally a calcium-bicarbonate or calcium-sulfate type, except for well DW-203 which contains sodium-bicarbonate type water. DW-203 is relatively deep (greater than 100 feet) compared to other wells in the area, and probably intercepts a different ground-water system.

Stiff diagrams show alluvial ground water in the area between Silver Bow and Miles Crossing is typically a calcium-bicarbonate type. Monitoring wells GS-03 and GS-04 are slightly atypical in that they exhibit near-equal ratios of sodium and calcium.

3.1.4.4 Deer Lodge Valley

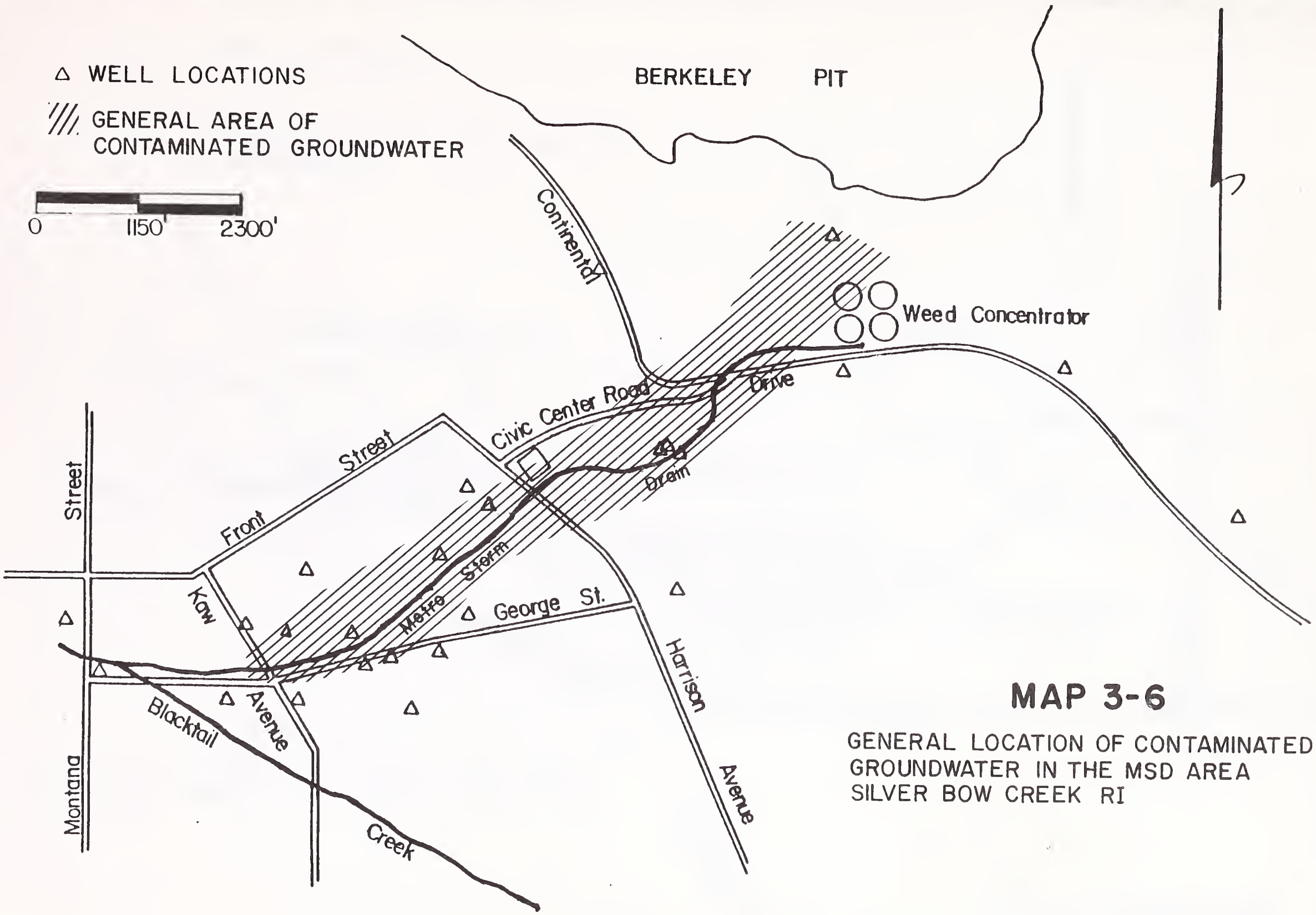
The Stiff diagrams for the southern Deer Lodge Valley ground water show a calcium-bicarbonate or calcium-sulfate type water. Ground-water samples collected from the three shallow wells in the Deer Lodge Valley north of the Warm Springs Ponds indicate shallow alluvial ground water is a calcium-bicarbonate type. However, well DW-504 displayed a calcium-sulfate type water. Apparently DW-504 intercepts distinctly different water than the shallower wells, or owner-reported well construction deficiencies affected water quality.

3.2 CONTAMINANT SOURCES

This section discusses both measured and potential sources of contaminated, shallow alluvial ground water found during this RI. Seven potential sources were evaluated:

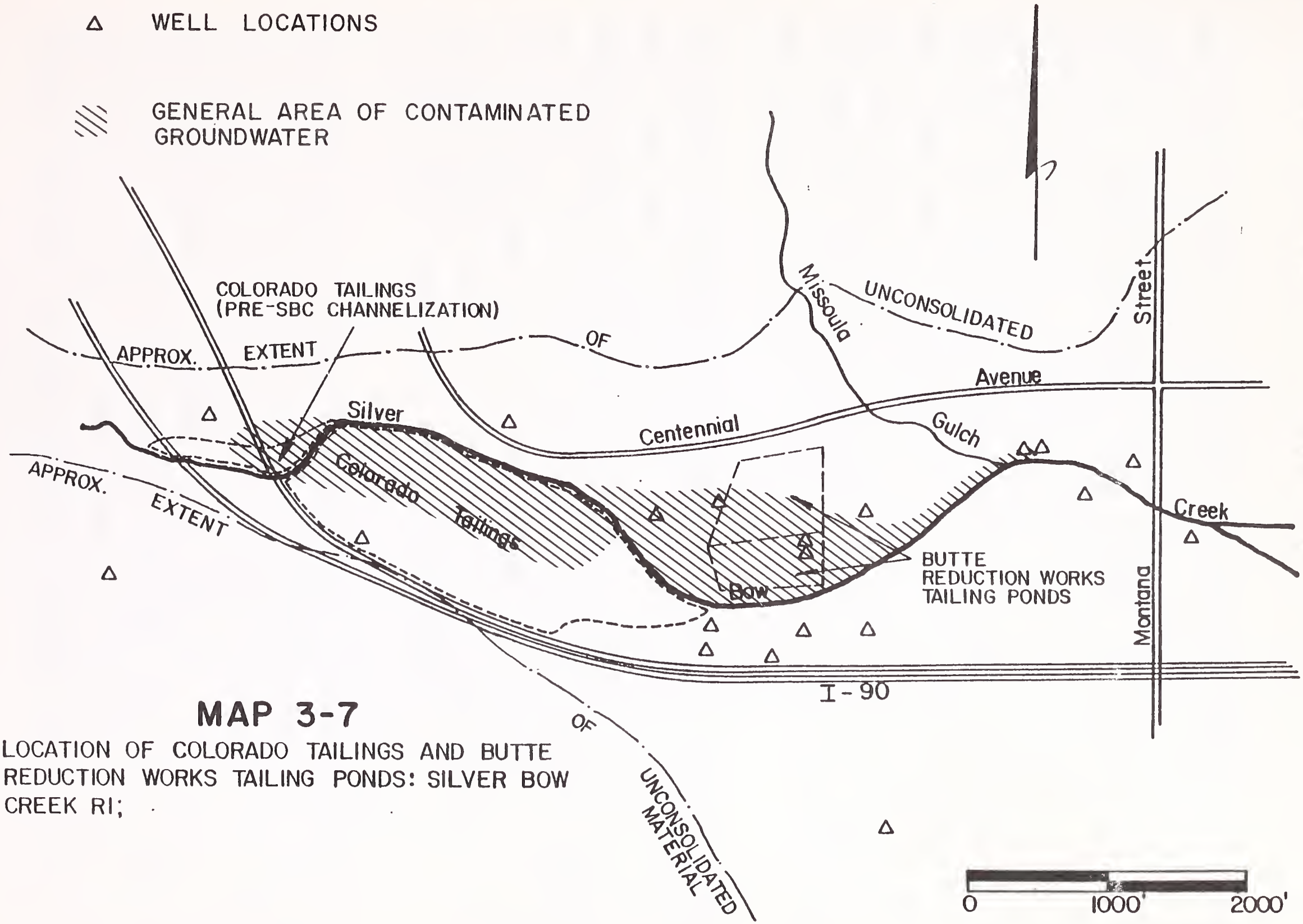
(1) Historic buried tailings in the upper MSD area, including those from the Parrot Smelter.
(2) Historic process or discharge waters from the Weed Concentrator Complex.
(3) Historic buried tailings in the vicinity of the STP-Butte Reduction Works.
(4) The Colorado Tailings deposit.
(5) The Anaconda Pole Treatment Plant near Rocker.
(6) The Ramsay Flats deposits.
(7) Fluvially deposited streambank deposits along Silver Bow Creek and the Clark Fork River.

Areas of contaminated alluvial ground water identified during the SBC RI were in the vicinity of the MSD, upper Silver Bow Creek between Montana Street and the western end of the Colorado Tailings, and the Ramsay Flats area. Maps 3-6 and 3-7 delineate the two major areas (MSD and Upper Silver Bow Creek) of ground-water contamination based on copper and zinc concentrations and specific conductivity values. These two areas were identified in the Surface Water and Point Source Investigation (Appendix A) as contributing contaminated ground water to Silver Bow Creek.



MAP 3-6

GENERAL LOCATION OF CONTAMINATED GROUNDWATER IN THE MSD AREA SILVER BOW CREEK RI



MAP 3-7

LOCATION OF COLORADO TAILINGS AND BUTTE REDUCTION WORKS TAILING PONDS: SILVER BOW CREEK RI;

Ground-water quality is degraded by dissolved metals in an area along the MSD from the Weed Concentrator to near Kaw Avenue, including zinc, copper, manganese, iron, cadmium, and arsenic (Map 3-6). Ground-water quality improves laterally away from the MSD and exhibits near-background levels within 1500 feet on either side of the MSD. The area of most degraded ground water is slightly southeast of the upper MSD and appears to coincide with the location of the historic Silver Bow Creek channel. Ground-water quality generally improves with depth, although a deep (> 150 feet) component of poor quality ground water is present near the upper end of the MSD.

Two areas of degraded ground water are present within the upper Silver Bow Creek alluvial system (Map 3-7). The first is located between Missoula Gulch and the Colorado Tailings, north of Silver Bow Creek. Ground-water quality in this area exhibits extremely elevated concentrations of most parameters measured. The most degraded ground water in the area is in the upper portion of the aquifer; quality apparently improves with depth.

The second area of degraded ground-water quality is beneath and adjacent to the Colorado Tailings. Although this site was not specifically evaluated during the RI, data collected by the Montana Bureau of Mines and Geology (Duaime et al. 1984) suggest that ground water beneath the Colorado Tailings area is contaminated with several metals. An area of poor quality ground water also is present northwest of the Colorado Tailings, across Silver Bow

Creek. This area was part of the Colorado Tailings prior to re-channelization of the stream during the construction of Interstate 90, and the extent of this poor quality ground water is unknown.

Monitoring wells and lysimeters completed at shallower depths in the saturated zone of the Silver Bow Creek alluvial aquifer in and near Ramsay Flats exhibit water quality degradation by dissolved arsenic, copper, and zinc. Dissolved metals and sulfate concentrations were several times higher in the shallower portion of the aquifer than in adjacent wells completed in a deeper portion of the aquifer, indicating the source is likely the overlying tailings. Alluvial ground-water quality appears to improve with depth, which may indicate dilution by better quality ground water from lateral inflow or geochemical attenuation mechanisms.

3.2.1 Buried Tailings In The Upper MSD Area

Sources of ground-water contamination identified during the SBC RI include buried tailing deposits in the upper MSD area. Historic aerial photographs indicate an expansive area of tailings deposition along the MSD (Map 2-1). Thicker deposits were located at historic smelters and included a large tailings pond a few hundred yards north and east of the Weed Concentrator and the Parrot Tailings, underlying the present City/County Shop complex. The Parrot Tailings are buried beneath approximately 15 feet of fill material; based on air photos, they cover an area of approximately 30 acres. Other upgradient buried tailings associated with historic smelters in the

Meaderville area also may be a source of contaminants to subjacent ground water. These tailings deposits are located beneath and adjacent to the Weed Concentrator complex on the south edge of the Berkeley Pit.

The Parrot Smelter tailings represent a significant source of ground-water contamination. Based on subsurface materials collected during drilling (Wells GS-07 and GS-10), these tailings have elevated metals concentrations. The present ground-water table intercepts the base of these tailings and their location coincides very closely with areas of contaminated ground water.

The Berkeley Pit is currently controlling ground-water movement in upper reaches of the MSD area. If and when historic ground-water flow lines are re-established, buried tailings deposits along the MSD and in upgradient areas could become saturated. This may significantly degrade ground water, increasing the affected area and eventually, Silver Bow Creek.

3.2.2 Historic Operations of The Weed Concentrator

Process water contained on-site or discharged from the Weed Concentrator complex upgradient of the MSD area may have been a source of ground-water contamination when the facility was operational. Impoundments may have leaked process water of unknown quality into the alluvial aquifer, possibly leaching buried tailings.

RI and historic data show ground-water elevations in the upper MSD area have dropped significantly since discharges from the Weed Concentrator were discontinued in 1983, which suggests that the discharge was a source of ground-water recharge during operation. The ground-water mound resulting from this discharge may have saturated a thicker portion of the Parrot Tailings previously described, or may have been a source of ground-water contamination itself.

Future discharges from the Weed Concentrator may affect ground-water quality in the study area. Such discharges may leach metals in buried tailings deposits into underlying ground water or, conceivably, the entire buried tailing deposit could resaturate and become a much more significant contaminant source.

3.2.3 Buried Tailings in the STP Vicinity

Data collected during the RI also suggest a source of ground-water contamination between Montana Street and the eastern end of the Colorado tailings. Historic aerial photographs indicate an extensive series of tailing ponds existed from just below Montana Street to and including the Colorado Tailings. This series included the historic Butte Reduction Works tailings impoundments which have subsequently been partially buried (Map 2-2). Ground-water quality data from several monitoring wells suggest a source of contaminants coinciding with the location of these tailing impoundments. The contaminant source in this area probably is mine and mill tailings

which collected behind the impoundments, although no samples of this material were collected or analyzed.

A shallow ground-water system is present in the vicinity and may intercept the tailings deposit and contaminate the local ground-water system. Infiltration of precipitation and/or snowmelt through the tailings deposits also may contaminate the aquifer.

Other evidence that these tailings were a contaminant source includes improvements in ground-water quality with depth, indicating a contaminant source overlying the ground-water system in the area; and significant degradation of ground-water quality between upgradient and downgradient wells. The extent of ground-water contamination from this source is unknown, but the poor-quality water periodically pumped from the Butte Sewage Treatment Plant (STP) dewatering well is likely derived from this source (Appendix A, Surface Water and Point Source).

3.2.4 The Colorado Tailings Deposit

This evaluation was based primarily on information and data presented by previous investigators of the site. The Colorado Tailings site was excluded from the Silver Bow Creek RI because MDHES thought the existing data base was adequate and the SBC RI produced data from areas adjacent to the Colorado Tailings which also were used in the evaluation of the site.

The Colorado Tailings deposit is located approximately one-half mile southwest of the city of Butte, Montana. It consists of approximately 44 acres of mine and mill tailings located in the floodplain of Silver Bow Creek. Based on existing information, the average depth of the tailings is estimated to be 5 to 6 feet, representing a corresponding volume of between 355,000 and 426,000 cubic yards.

Mill tailings and contaminated soils are the predominant contaminant sources at the Colorado Tailings. A peat layer underlies most of the tailings deposit and ranges in thickness from 6 to 24 inches, averaging approximately 1 foot (Duaime, et al. 1982). The peat layer apparently thins toward the northwest across the Colorado Tailings. Physical analyses of tailings samples indicate the material is approximtely 90% sand-size particles (Hydrometrics 1983e).

Thornell (1985) evaluated metals concentrations at various depths in the Colorado Tailings in one boring. Results of the analyses indicated the underlying peat layer contains high concentrations of copper, iron, manganese, zinc, and lead (Table 3-4) relative to the overlying tailings and the alluvial material below, which indicates the peat layer underlying the Colorado Tailings is concentrating some metals leached downward from the tailings.

A shallow ground-water system is present throughout the year at the Colorado Tailings. Ponded water on the surface of the tailings is a common occurrence following snowmelt or rainfall, which undoubtedly

TABLE 3-4

COLORADO TAILINGS - COMPOSITION PROFILE

Total Metals[a] At A Site in the Northwest Corner of the Colorado Tailings[b]

Depth (ft)	Material	Fe	Mn	Cu	Pb	Zn	As
0-1.8	Tailings	10,200	360	663	480	2,430	678
1.8-2.6	Tailings	15,200	368	997	600	3,310	1,300
2.6-4.5	Tailings	19,400	262	2,050	640	2,880	2,320
2.6-4.5	Tailings	24,300	262	1,950	890	4,630	2,960
4.5-6.0	Tailings	19,500	1,540	2,450	1,050	4,360	1,780
4.5-6.0	Tailings	18,900	2,180	2,990	1,140	5,630	1,810
6.0-7.0	Tailings	24,000	8,000	6,730	2,570	8,230	1,700
6.0-7.0	Tailings	24,900	8,400	6,630	2,740	8,090	1,390
7.0-7.5	Peat	54,500	12,800	14,300	6,370	14,700	1,550
7.0-7.5	Peat	47,100	12,100	13,400	6,750	14,800	1,280
7.5-8.5	Peat	50,500	28,600	2,430	14,900	22,500	523
7.5-8.5	Peat	48,000	26,500	2,510	13,700	20,800	504
8.5-9.5	Peat	44,500	11,200	1,730	8,980	17,400	504
8.5-9.5	Peat	40,900	12,400	1,760	8,900	13,800	565
9.5-10.0	Alluvium	12,600	242	188	28	300	

Note: [a]All Results Expressed in µg/g.
[b]Montana Bureau of Mines and Geology (Thornell 1985)

infiltrates through the tailings to the ground water. The base water table elevation is generally 2 to 5 feet below the tailings surface and appears to fluctuate in response to the water surface elevation of Silver Bow Creek.

Ground-water movement through the tailings is generally from the southeast to the northwest along a gradient of one foot in 100 feet (Hydrometrics, 1983e), eventually discharging into Silver Bow Creek.

Duaime, et al. (1984) report ground-water quality in the Colorado Tailings degrades significantly from south to north and from east to west. Upgradient wells southeast of the site exhibit considerably lower concentrations than those completed in the tailings deposit. The highest concentrations occur near the discharge area (northwest corner) of the tailings.

These data support the contention that ground water in the Colorado Tailings degrades measurably as it moves to its downgradient discharge area in the northwestern portion of the tailings deposit. The highest dissolved metals concentrations were measured in the northwestern portion of the tailings: arsenic (0.26 mg/l), cadmium (0.66 mg/l, copper (78 mg/l), iron (343 mg/l), lead (0.61 mg/l), and manganese (73.3 mg/l). Associated pH values were in the 3.0 to 3.5 range; specific conductivity values were in excess of 3,500 µmhos/cm. Duaime, et al. (1984) reported little significant variation in ground-water chemistry with depth in the Colorado Tailings. They

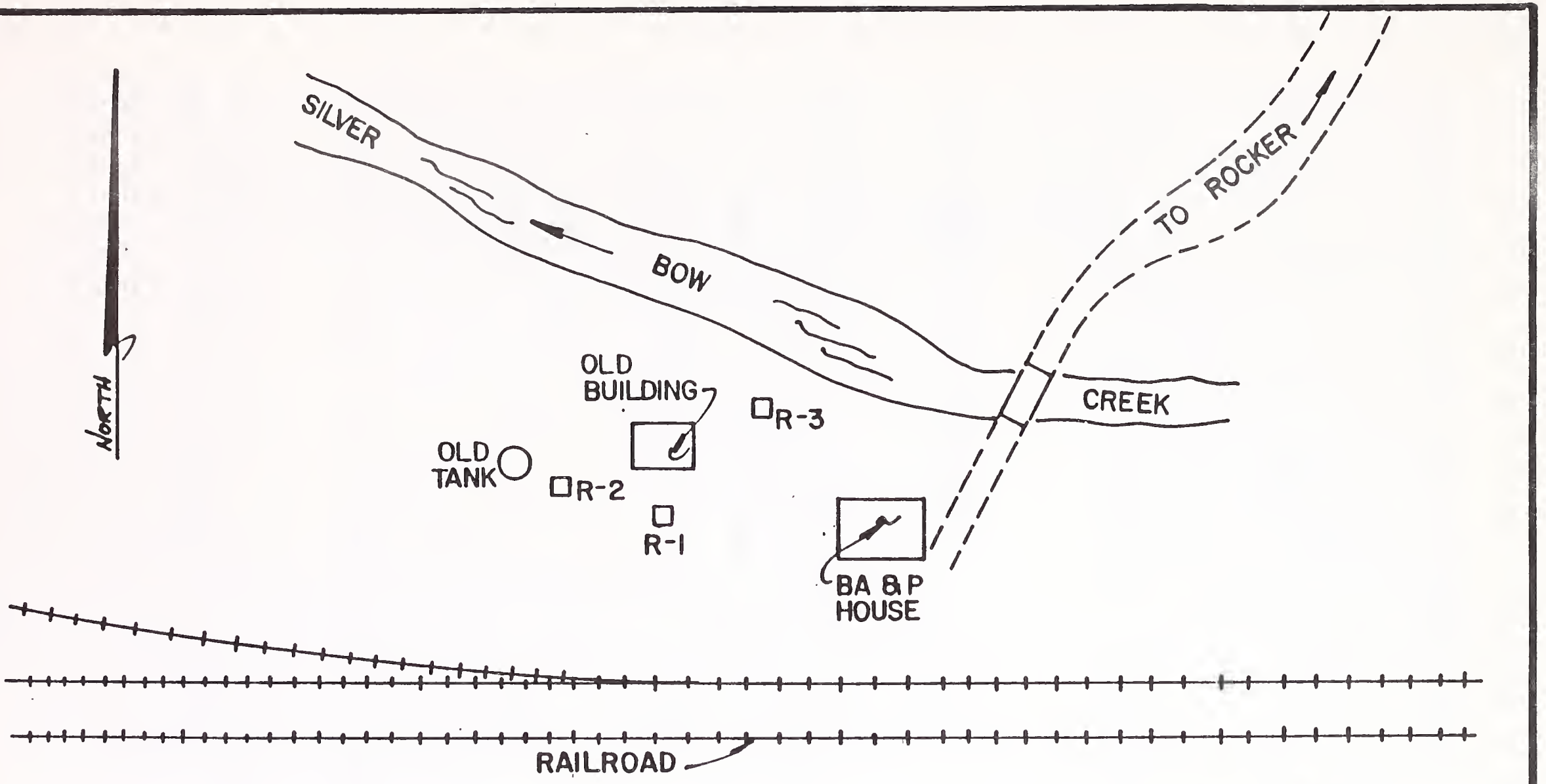
conclude that the deeper alluvial aquifer has been and is being contaminated by the Colorado Tailings.

Surface water adjacent to and downstream from the Colorado Tailings also may be significantly affected by flood events on Silver Bow Creek. Floods substantially greater than 300 cfs could cause major releases of impounded tailings to the creek. Insufficient data are available to quantify impacts of the Colorado Tailings on Silver Bow Creek water quality during flood flows. Flood flows in Silver Bow Creek historically breached a berm on the east end of the Colorado Tailings, creating channels across the tailings and undoubtedly entraining sediment. Because of this, riprap was placed along the Silver Bow Creek channel at the east end of the Colorado Tailings. This action has apparently been successful in maintaining the creek in its channel, at least during moderately high flow events.

Large flood events today probably would still inundate the Colorado Tailings and cause scour and entrainment of tailings material by Silver Bow Creek below the site. The impact of such events on the quality of water in Silver Bow Creek is unknown.

3.2.5 The Anaconda Pole Treatment Plant

Several soil grab samples were collected from the vicinity of the historic Anaconda Pole Treatment Plant timber-treating facility near Rocker (Map 3-8). Arsenic was used as a wood preservative



MAP 3-8

MATERIAL SAMPLE LOCATIONS: HISTORIC ANACONDA POLE AND TREATMENT COMPANY SITE: SILVER BOW CREEK RI

0 50' 100'

APPROX. SCALE

at this site and may have affected soils and local ground water. Extremely elevated arsenic levels were found in grab samples from the mine timber treating plant location; for example, the arsenic concentration in one sample had total arsenic levels in excess of 1%, which is several orders of magnitude above background. Domestic wells in the area do not appear to be impacted by the plant site, although ground water immediately downgradient from the site was not sampled.

3.2.6 Ramsay Flats Tailings

The Ramsay Flats is a large (approximately 160 acres) deposit of fluvially transported tailings mixed with natural sediment, located along Silver Bow Creek between Silver Bow and Dawson. Figure 3-9 is a fence diagram of a portion of Ramsay Flats showing tailings and near-surface lithology. The topography of Ramsay Flats prior to tailings deposition was irregular. Subsurface lithology contained lenses of sand and silt, typical of alluvial deposits. Ancestral Silver Bow Creek appears to have transected Ramsay Flats near the center of the present day deposit, as evidenced by a trace of alluvial gravels encountered at this locale.

The Ramsay Flats area was studied extensively, and the results and conclusions regarding physical or chemical characteristics can be applied to other parts of the project area which contain similar exposed tailing materials.

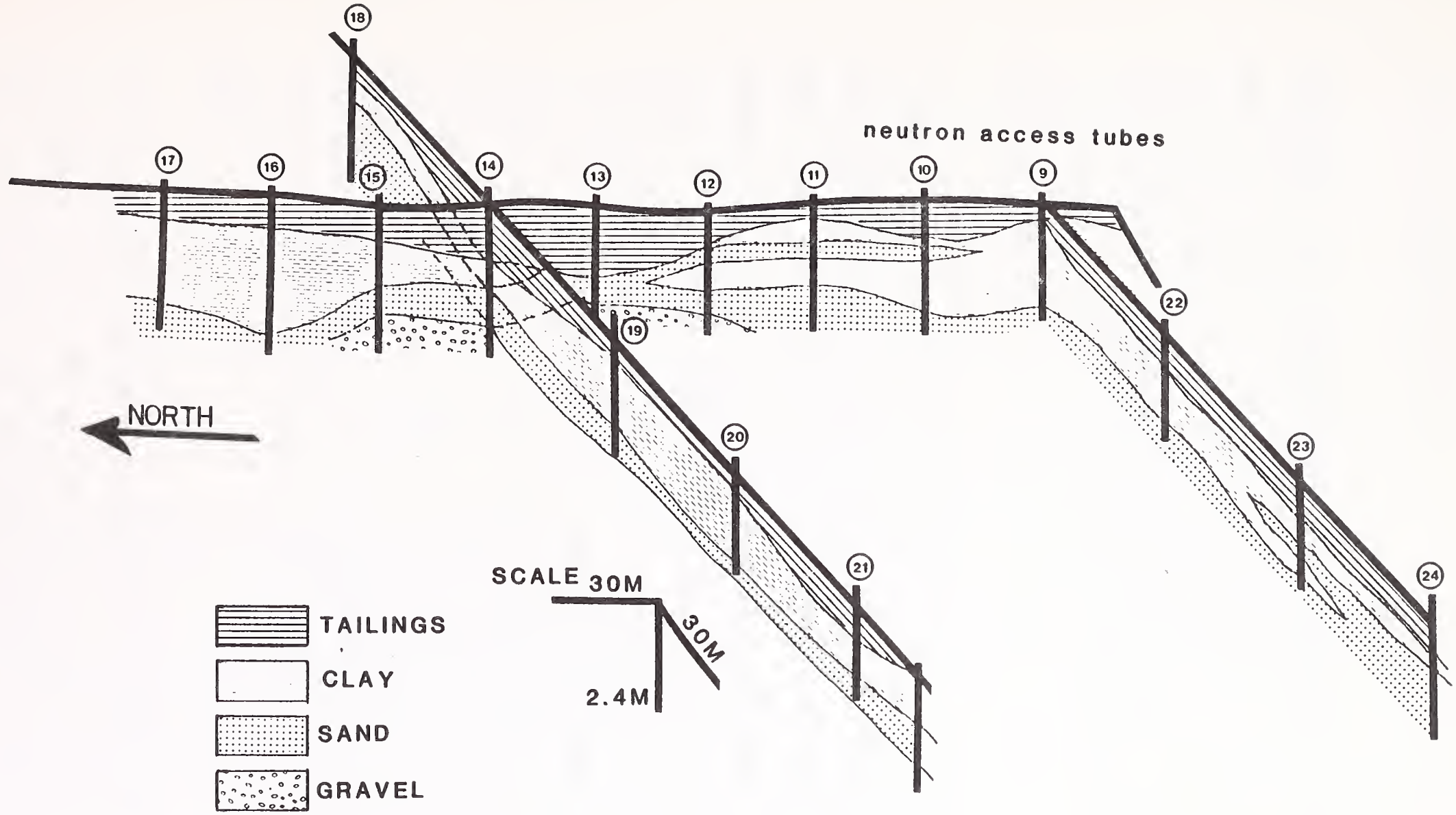


FIGURE 3-9

LITHOLOGIC FENCE DIAGRAM OF RAMSAY FLATS

3.2.6.1 Metals Levels

Tailings are suspected to have affected surface and ground-water quality primarily due to contamination with arsenic, copper, zinc, cadmium, lead, iron, and manganese. Tailings may contribute to water quality degradation in two ways: by their higher average total metals levels, and by their tendency to increase metal mobility by lowering pH.

Across the entire RI site, 46 tailing samples were collected, and they varied in chemical and physical character. Mean tailings pH was 4.73, and mean SC was 5860 micromhos/cm, reflecting the acid-forming reaction of sulfide materials and accumulation of sulfate salts. Tailings were mostly sandy or silty textured with average sand content of 54.6% and average clay content of just 9.6%. Sandier tailing materials, which presumably were deposited in higher energy reaches of Silver Bow Creek, have a tendency to be higher in pyritic sulfur because higher density particles (like metallic sulfides) tend to settle from suspension with larger grain-sizes of suspended sediment. As a consequence of higher pyrite content and lower buffering capacity, the sandier tailings tend to have lower pH.

Total sulfur averaged nearly 0.5% in the tailings. Sulfide sulfur averaged 29% of the total (1320 µg/g), while sulfate accounted for 51%. The extent of sulfide reaction in the tailing samples appears to be relatively complete after 70 or more years of weathering.

Total copper content in 15 tailings samples averaged 2350 micrograms per gram (µg/g), or about 60 times geochemical background (Table 3-5). Average levels of saturation extractable copper in tailings were nearly 20 µg/g on a soil weight basis (geometric mean). In soils buried by tailings, the geometric mean soluble copper was 1.3 µg/g. The distribution of soluble copper was strongly skewed, with a maximum value of nearly 2000 micrograms of copper per gram of soil in tailings. Soluble copper levels in tailings are several orders of magnitude in excess of acceptable levels in water; therefore, a small amount of leachate from the tailings could constitute a significant source of contamination to surface- or ground-water.

TABLE 3-5
GEOCHEMICAL BACKGROUND CONCENTRATIONS FOR SOILS
IN THE WESTERN UNITED STATES[a]
(µg/g)

	Mean[b]	Mean + 1 Standard Deviation[c]	Townsend, Montana Soils[d]
Copper	21	43	21
Zinc	55	98	95
Iron	21,000	41,000	--
Arsenic	6	11	3.4
Lead	17	31	55
Cadmium	0.2	0.5	1.4
Manganese	380	752	625

(a) Data From: Shacklette and Boerngen 1984.

(b) Means and Standard Deviations are Geometric to account for log-normal distributions.

(c) Upper limit of geochemical background used for comparison to RI data.

(d) Tetra Tech (1985) background soils from Townsend site, 1" depth.

Maximum total copper in tailings was 6025 µg/g. Levels of total copper in soils beneath tailings were also elevated far above geochemical background, indicating that copper migration has occurred out of tailings into underlying soil materials.

Average cadmium content in tailings samples was 13.4 µg/g, which is roughly 27 times background geochemical levels (Table 3-5). Total cadmium was as high as 58 µg/g in a buried soil material. Soluble cadmium averaged 0.54 µg/g (geometric mean) in tailings and 0.66 in underlying soil materials.

Total iron averaged 18,620 µg/g (geometric mean) and did not vary significantly between contaminated and uncontaminated samples. As a primary constituent of soils, iron concentrations would not be expected to change in response to tailings deposition, but soluble and exchangeable iron are strongly affected by the influence of tailings on pH. The correlation of soluble iron with pH is significant, and soluble iron influences the solubility of other metals.

Total lead in 15 tailings samples averaged 989 µg/g of soil, or roughly 33 times higher than geochemical background (Table 3-5). Lead in buried soils was 98 µg/g (geometric mean), three times the geochemical background. Saturation extractable lead was 0.72 and 0.91 µg/g in tailings and buried soils, respectively. Despite highly elevated levels in tailings, lead content in the saturation extract was not as excessive as other metals, probably due to its low solubility.

Total manganese in tailings and buried soil averaged 2237 and 602 µg/g, respectively. Manganese is a constituent of many common primary and gangue minerals which may not be fully digested by the nitric-peroxide total analysis laboratory method used for the RI, so these concentrations may be underestimated. Approximate geochemical background for total manganese is 750 ug/g (Table 3-5). Geometric mean soluble manganese was 26.3 and 2.57 µg/g in tailings and soil, respectively, while exchangeable manganese was 138 and 25.1 µg/g.

The geometric mean total zinc was 3070 and 336 µg/g in tailings and buried soils, respectively. Average geochemical background is about 100 µg/g (Table 3-5), indicating zinc is highly elevated in tailings. Soluble zinc in tailings averaged 36.3 µg/g, with a maximum value of 1738 µg/g soluble zinc.

Geometric mean total arsenic was 399 and 53 µg/g in tailings and soils, respectively. Typical geochemical background is 11 µg/g, but might be higher locally due to the dominance of arsenic-bearing minerals in Butte area ores. Even using a higher background level of 20 µg/g, arsenic is greatly enriched in tailings and in buried soils.

3.2.6.2 Surface Salts

During the summer months, a bluish surface salt stained the floodplain surface in many areas. Samples of this material collected on

Ramsay Flats (Site 27) had 6780 micrograms soluble copper per gram of dry soil weight. Another sample of surface salt had 98,500 µg/g (nearly 10%) total copper, 22,200 µg/g total zinc, 6,800 µg/g total iron, 19,700 µg/g total manganese, 48.3 µg/g total cadmium, and 149 µg/g total lead. Another sample was obtained 20 feet from the Clark Fork River near the town of Warm Springs (Site 29). The bluish-colored salt had 7% total copper, 3% zinc, 1% manganese, and .012% cadmium.

Likely constituents of the surface salt layer includes the ferrous sulfate mineral suite melanterite $FeSO_4 \cdot 7H_2O$, rozenite $FeSO_4 \cdot 5H_2O$, and szomolnokite $FeSO_4 \cdot H_2O$; or cuprian siderotil $(Cu, Fe)SO_4 \cdot 5H_2O$; malachite $(Cu_2(OH)_2CO_3)$; hopeite $(Zn_3(PO_4)_2 \cdot 4H_2O)$, anglesite $(PbSO_4)$; and gypsum $(CaSO_4 \cdot 2H_2O)$. A complex mixture of hydrated sulfates, carbonates, phosphates, and hydroxy-carbonates may coexist with a substantial amount of isomorphous ion substitution and solid solution (Nordstrom 1982). Further mineralogical investigation may be required to determine the kinds of evaporite minerals forming on the tailings surface.

3.2.7 Other Fluvially-Deposited and Streambank Tailings

Several areas adjacent to Silver Bow Creek and the Clark Fork River contain substantial tailing deposits which are underlain by a relatively shallow alluvial aquifer. These areas were mapped and are presented in Appendix D, Part 2 (Riparian Vegetation Investigation).

Streambank tailings in the study area are typically discontinuous deposits, less than 2 feet thick, and consist primarily of sand-size particles. These deposits probably were a result of tailings being fed directly into the stream, or being entrained during flooding or accidental breakage of tailings impoundments. As a group, streambank tailings in the upper reaches of Silver Bow Creek had the highest metal concentrations of all samples characterized. This differentiation is probably due to the tendency for coarser-grained and higher-density tailings materials (e.g., pyrite) to drop from suspension relatively quickly, resulting in more deposition in areas with higher stream gradients.

Tailings sampled typically exhibited low pH (2.9 to 6.0) and elevated salinity (1 to 12 mmhos/cm). The samples were typically sandy and had extremely elevated metal levels.

Maximum concentrations of soluble metals usually were found either at the surface or at the base of the tailings, or occasionally in the soil layer directly beneath them. Metals flux is apparently occurring in response to the dominant water flux direction in each soil. Frequently, extractable metal levels were highest in soils just below the tailings. The higher cation exchange capacity of the buried soils likely had a larger retention capacity, accounting for the higher exchangeable levels.

The Deer Lodge Valley has two distinct types of tailings and waste deposits: flood-deposited tailings in the Silver Bow Creek and

Clark Fork River floodplains (similar to those found upstream) and irrigation-contaminated agricultural lands. Floodplain sites had extremely high metal levels, as did those upstream. However, the chemistry of flood-deposited tailings does not appear to change with increasing distance downstream, and the deposits are thinner and more discontinuous, probably in response to decreasing stream gradient and dilution by natural sediment.

Contaminated agricultural lands have less apparent contamination than do floodplain tailings, and are sparsely to fully vegetated. They are used for crop and livestock production, and potential exists for bioaccumulation of metals from these lands. Paired soil samples collected above and below old irrigation ditches showed significantly higher metals concentrations below the ditches. Frequently, the above-ditch sample exhibited levels slightly elevated from background, probably due to aerial deposition. These data indicate that irrigation water has contaminated a great deal of agricultural land in the Deer Lodge Valley.

A ground-water plume identified north of the Warm Springs Ponds (see Appendix C, Warm Springs Ponds Report) probably is limited, and certainly is not present in wells DW-501 and DW-502, located 1-1/2 to 2 miles downgradient from the Warm Springs Ponds (Map 1-5 Over Size).

Floodplain tailings are proximal to surface water and are a potential contaminant source through bank storage release, shallow

ground-water recharge, entrainment during high stream flows, and surface runoff from metal-rich saline deposits. No evidence suggests that the widely dispersed mine and mill tailings in the study area measurably affect shallow domestic wells. If degraded ground water is present, it is likely restricted to local, shallow alluvial deposits associated with the floodplain tailings. Floodplain tailings deposits are quite extensive in the Deer Lodge Valley and occur at least as far downstream as Gold Creek, and probably further (Moore 1985).

Because the RI was conducted during a drier-than-normal year, the impact of these tailing deposits on subjacent ground-water quality may not have been completely evaluated. During wetter years, greater infiltration of precipitation and/or snowmelt may leach more metals into underlying ground water. Additionally, ground-water levels may rise into tailings and become degraded by contact with the deposits.

3.3 CONTAMINANT TRANSPORT MECHANISMS

Several mechanisms may be responsible for mobilizing contaminants from source materials or areas to surface and ground waters in the RI study area:

(1) Direct infiltration of precipitation or snowmelt through tailings, leaching contaminants into the underlying ground-water. This mechanism was studied in detail at the Ramsay Flats tailings as part of the RI.

(2) Ground-water flux through tailings which are below the water table, solubilizing contaminants and transporting them along ground-water flow paths. No specific studies were done to quantify this mechanism; however, RI data collected around buried tailings (Parrot Smelter and Butte Reduction Works) was used as evidence of this process.

(3) Capillary action in tailings driving metallic salts to the surface, which are then available for entrainment or re-solubilization by surface runoff. No studies were performed to quantify this mechanism, but surface salts on Ramsay Flats were characterized as part of this RI (Section 3.2.6).

(4) Direct erosion and entrainment of streamside tailings by intense precipitation and soil detachment, or by rises in stream stage. Appendix A (Surface Water and Point Source) discusses this mechanism to the extent that it was observed and measured during the RI.

(5) Hydraulic controls, which include bank storage releases following a decrease in stream stage (not evaluated), artificial ground-water mounding caused by concentrator operations, and geologic structures affecting ground-water movement. These controls can influence the significance of some of the previous mechanisms.

3.3.1 Infiltration Through Surface Tailings

An extensive study of the mechanisms working on exposed tailings at Ramsay Flats was performed during this RI. This study examined porewater chemistry in the vadose zone, soil water flux, and the mechanisms controlling contaminant flux into underlying ground water. Underlying ground-water chemistry then was examined to determine contaminant flux through the deposit. Tailings and underlying soil compositions were discussed previously in Section 3.2.6. The mobilities of the various parameters measured and the factors affecting their availability and transport were analyzed in detail, and these data were used to postualte transport processes occurring in the tailings.

3.3.1.1 Pore Water Chemistry

Two clusters of lysimeters were installed at Ramsay Flats (Map 2-5) to assess the chemical characteristics of the pore water in the vadose zone, identifying concentrations as a function of depth and

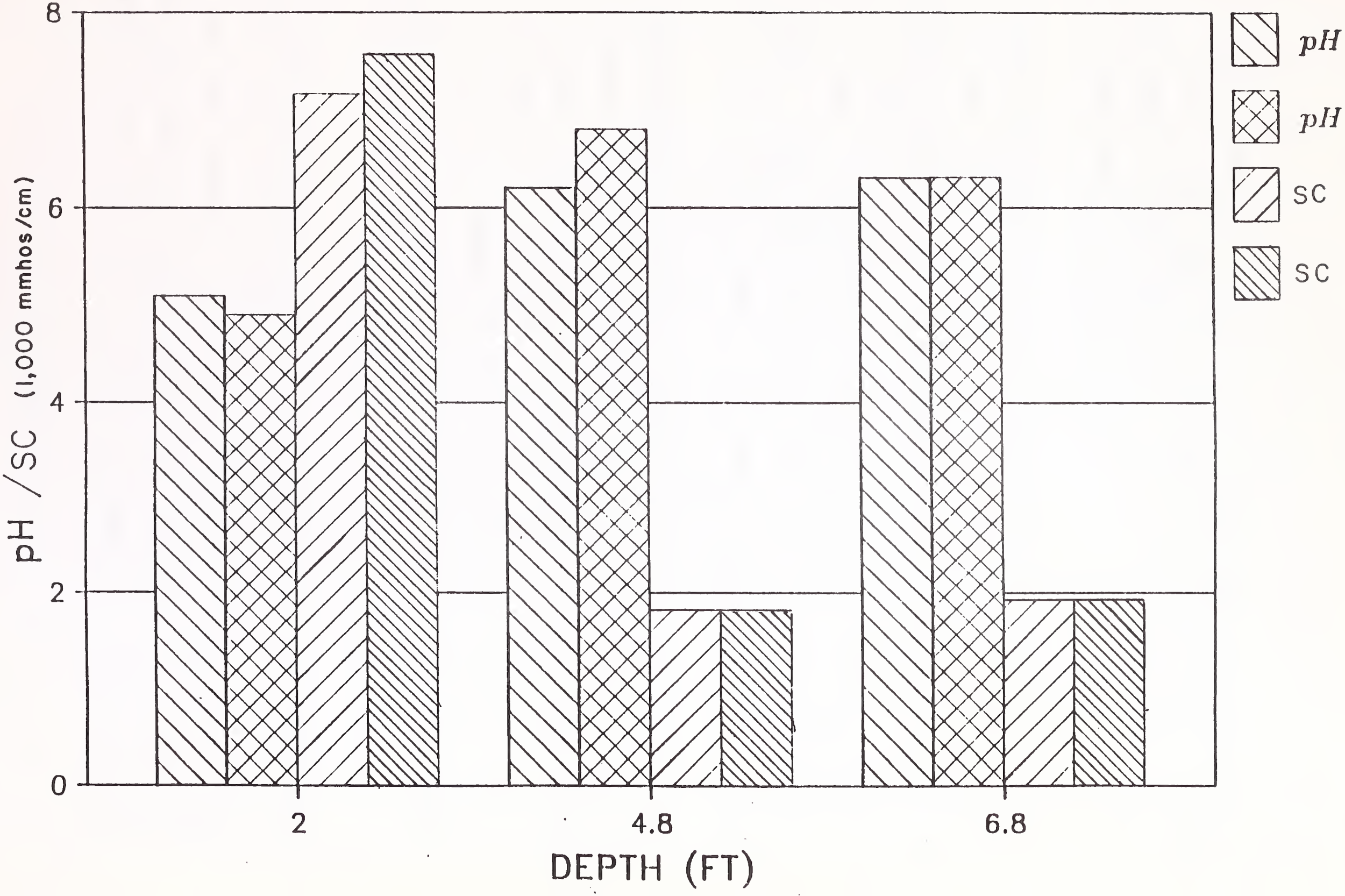
time and thus quantifying the metals produced and the tendency, if any, for metal flux or immobilization to occur.

The east cluster at Ramsay Flats had suction lysimeters at 3.5, 5.5, 7.5, and 9.5 feet. The deepest lysimeter (9.5 feet) was installed in the saturated zone. Samples were not obtained from the two uppermost lysimeters for analysis because soils were too dry or because inadequate soil contact was obtained. Samples were obtained from 7.5 and 9.5 feet in depth in the natural alluvium; their chemistry was similar in most regards and did not change through time.

The western cluster was installed at 2.0, 4.8, and 6.8 feet in depth. Samples were obtained consistently from each lysimeter. The shallowest lysimeter was installed in tailings material, whereas the others were in organically enriched silty material and coarse, sandy alluvium, respectively. Unlike the eastern cluster, chemical characteristics from the western cluster varied greatly with depth and time. Extremely elevated contaminant levels were found at the shallowest depth, but elevated levels did not appear to translate to the deeper depths.

Water pH and SC values indicate two contrasting waters at the west lysimeter cluster (Figure 3-10). The water from the tailings vadose zone had low pH (5.0) and elevated SC (7000-7500 micromhos/cm). Water in the organic layer and alluvium were similar to the east cluster, with pH of 6 to 6.5 and SC of 1900 micromhos/cm. Copper in

FIGURE 3-10 PLOT OF LYSIMETER pH AND SC DATA VS. DEPTH AT RAMSAY FLATS: WEST CLUSTER

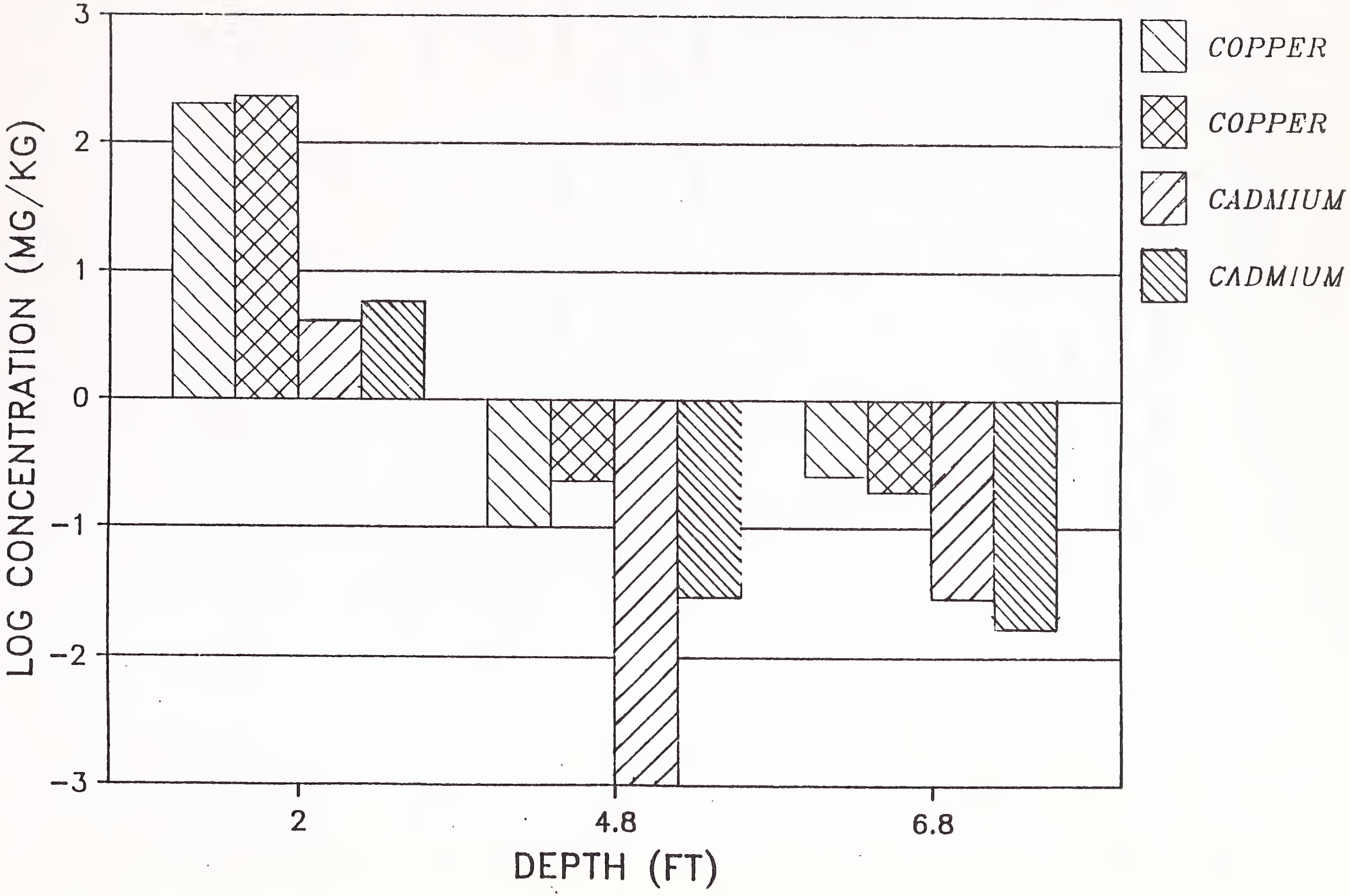


the tailings averaged over 200 mg/L; cadmium was 5.0 mg/L (Figure 3-11). Zinc at this depth was 1000 mg/L. At greater depth, copper was less than 0.3 mg/L and cadmium was less than 0.03 mg/L. Other metals showed similar declines.

Iron showed the opposite pattern; concentrations were lower in the tailings pore water and higher (8 to 15 mg/L) in the alluvium, apparently responding to differences in redox potential. Arsenic did not appear to follow the pattern of either copper, cadmium, zinc, or iron. Concentrations of arsenic were 0.01 to 0.04 mg/L at all depths. Lead was elevated in the shallow lysimeter samples (0.25 to 0.8 mg/L), compared to deeper samples (<0.01 mg/L). The dissimilarity in porewater chemistry between the shallow and deep samples indicates that either little water movement is occurring to cause a flux of metal, or that metals are being immobilized near the base of the tailings. The distribution of total metals in soils at the west cluster (Site 25) shows movement of metals to a depth of 20 or more inches into the underlying soil, indicating limited immobilization.

The dry year experienced in 1985, the lack of a soil water potential gradient, and no observed changes in soil water content all suggest that low water movement best accounts for the segregation of the vadose zone water and the saturated zone. Limited metal discharges to ground water also may be diluted by laterally influent ground water on the site.

FIGURE 3-11 PLOT OF COPPER AND CADMIUM VS. DEPTH
AT RAMSAY FLATS LYSIMETERS: WEST CLUSTER



3.3.1.2 Soil Water Flux

Clusters of four neutron access tubes were installed at Silver Bow (NP01 to NP04) (Map 2-3) and Rocker (NP05 to NP08) (Map 2-4), and 17 tubes were installed at Ramsay Flats (NP09 to NP24) (Map 2-5). Water content readings were made on several dates, and water content curves were prepared from these data. Two features of the water content curves from Ramsay Flats stand out: their extreme changes with depth, and their uniformity on different dates of measurement. Differences in water content through depth were related to textural differences. Tailings were typically sandy in texture and had water content near 20 to 30%. The underlying dark silty layer typically had water content near 50%, whereas the alluvial sands and gravels had water content near 20 to 30%. Very little change in water content occurred between dates, except for the deepest readings on tubes near Silver Bow Creek and in a few scattered locations. These water content differences could be ascribed to small water table fluctuations. The lack of water content change at the surface indicates one or more of the following:

- Most rainfall runs off the site;
- Most rainfall quickly evaporates from surface soil layers; or
- Rainfall moves through the profile to ground water quickly due to high hydraulic conductivity, and this is not reflected in water content changes.

Tensiometer data also were used to determine the direction of water flux. Tensiometer readings indicate little soil water potential gradient in the system, with all readings from 15 to 20 centibars. This water potential corresponds to the concept of "field capacity" for a medium to coarse-textured soil. Field capacity is the water content remaining after a soil freely drains by gravity for two to three days after an irrigation or rain event. Unsaturated hydraulic conductivity at this water potential can be high (1 to 25 cm/day), depending on soil texture. Water may have moved through these soils after a rain without being detected.

Changes in water content and measurement of water potential indicate that recharge of ground water may occur in Ramsay Flats during significant rainfall events. However, the frequency of tube reading and lack of spring and early summer moisture made it impossible to measure such recharge. To test the possibility of recharge occurring in wetter years, climatic data were fit to a water balance model developed to simulate the evaporative and hydraulic conditions of Ramsay Flats. The HAZWAL model was used only as an illustration; it was not calibrated for soil water characteristics of the site due to lack of data. Model output should be considered tentative until the model can be calibrated.

Using 1985 rainfall data from East Anaconda, very little drainage was predicted (<0.5 inches). The soil water content curves output from the model were similar to actual data in that little change occurred between dates except at the surface. When twice the actual

1985 rainfall was used in the model (16.4 inches, 30% above normal), a substantial amount of drainage (3.26 inches) from the soil is suggested (Figures 3-12 and 3-13).

3.3.1.3 Arsenic

Two laboratory extractions were used for arsenic in the Ramsay Flat samples. The Halvorson method used a strong acid (12 N HCl) extraction and is close to total arsenic. Since arsenate behaves much like phosphate, an extraction used for phosphate (the Bray extract) was used also. Bray extract arsenic levels were much lower than Halvorson extract.

Arsenic occurs in two or three oxidation states in soil, with As^{+5} (arsenate, AsO_4^{-3}; $HAsO_4^{-2}$; and $H_2AsO_4^{-1}$) being more common under oxidizing conditions, and As^{+3} (arsenite, AsO_2^{-1}) or rarely As being more common under reducing conditions (Kabata-Pendias and Pendias 1984). Arsenate can be reduced to arsenite at an Eh of 560mv and pH less than 2. Both oxidized and reduced forms of arsenic are possible in this system, though conditions found in the tailings heavily favor the oxidized forms. Arsenite is far more mobile in soil than arsenate. Arsenate, which behaves like phosphate, is often strongly adsorbed by iron and alumiunum oxides unless these oxides are hydrolysed at low Eh. Soil clays and organic matter also have a strong affinity for arsenate.

FIGURE 3-12 RAMSAY FLATS WATER BUDGET SIMULATION; SILVER BOW CREEK RI.

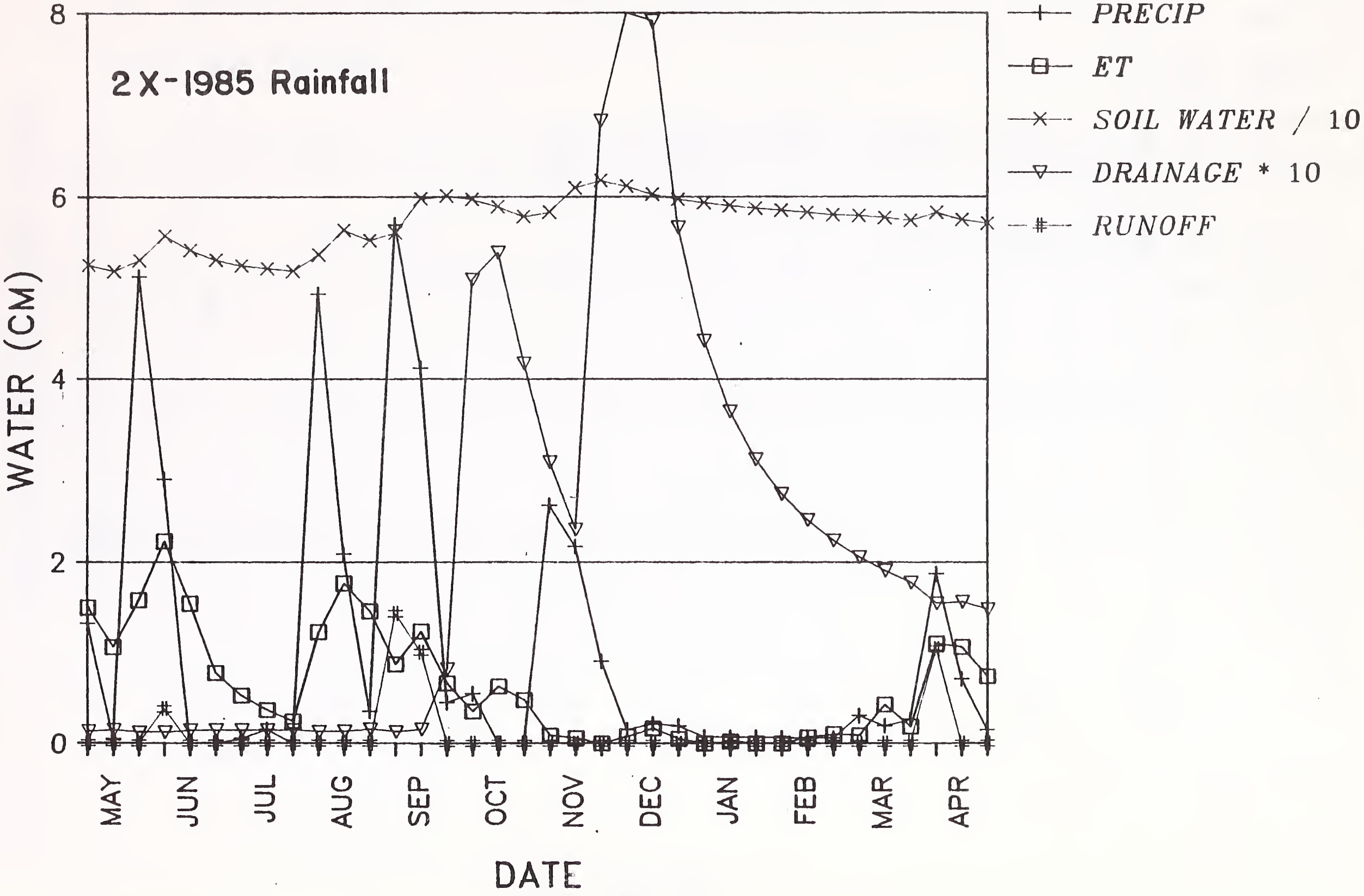
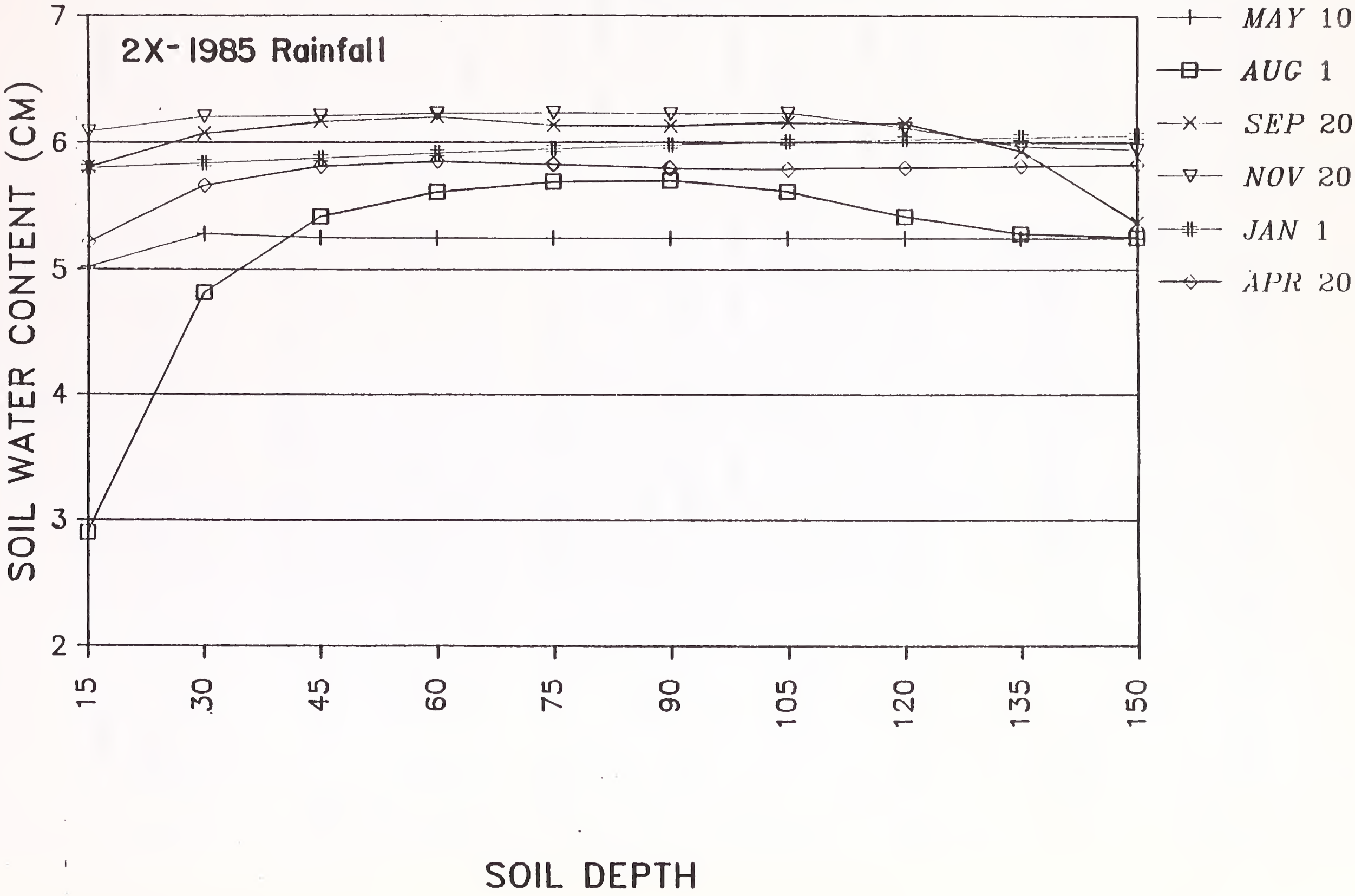


FIGURE 3-13 : PLOT OF SOIL WATER CONTENT VS. DEPTH AT RAMSAY FLATS ; SILVER BOW CREEK RI.



Total arsenic was correlated to SC (r=.31) and with depth. A multiple linear regression to predict total arsenic was developed for all tailings samples (Figure 3-14).

$$\log(\text{Total As}) = 3.22 - .142(\text{pH}) - .00971(\text{sand}) - .185(\text{Fesat}) + .264(\text{pyr.S}) - .025(\text{depth})$$

$$R^2 = 0.56$$

The inverse correlation of total arsenic with pH and iron saturation was likely due to the influence of pyritic sulfur on these parameters. The inverse relationship of sand to total arsenic may be due to the tendency of arsenic to adsorb to clays. The decrease in total arsenic with depth may either indicate an aerial depositional source or later fluvial depositional source of arsenic. Historic smelting activity in Butte, arsenic released from the Anaconda Pole Treatment Plant near Rocker, or arsenic from another industrial source may account for higher total arsenic at the surface.

Total arsenic appears to be related at least in part to the sulfide content of tailings (Figure 3-15) so that an aerial source may not fully account for its distribution. Total arsenic appears to range from 10 to 100% of total pyritic sulfur in these materials. Many arsenic-containing sulfides were common in Butte ores.

The partitioning of arsenic into the extractable fraction was not well correlated to other variables. The ratio of Bray arsenic to total appeared to increase slightly at higher pH, although Bray

FIGURE 3-14 : TOTAL ARSENIC MLR MODEL : SILVER BOW CREEK RI.

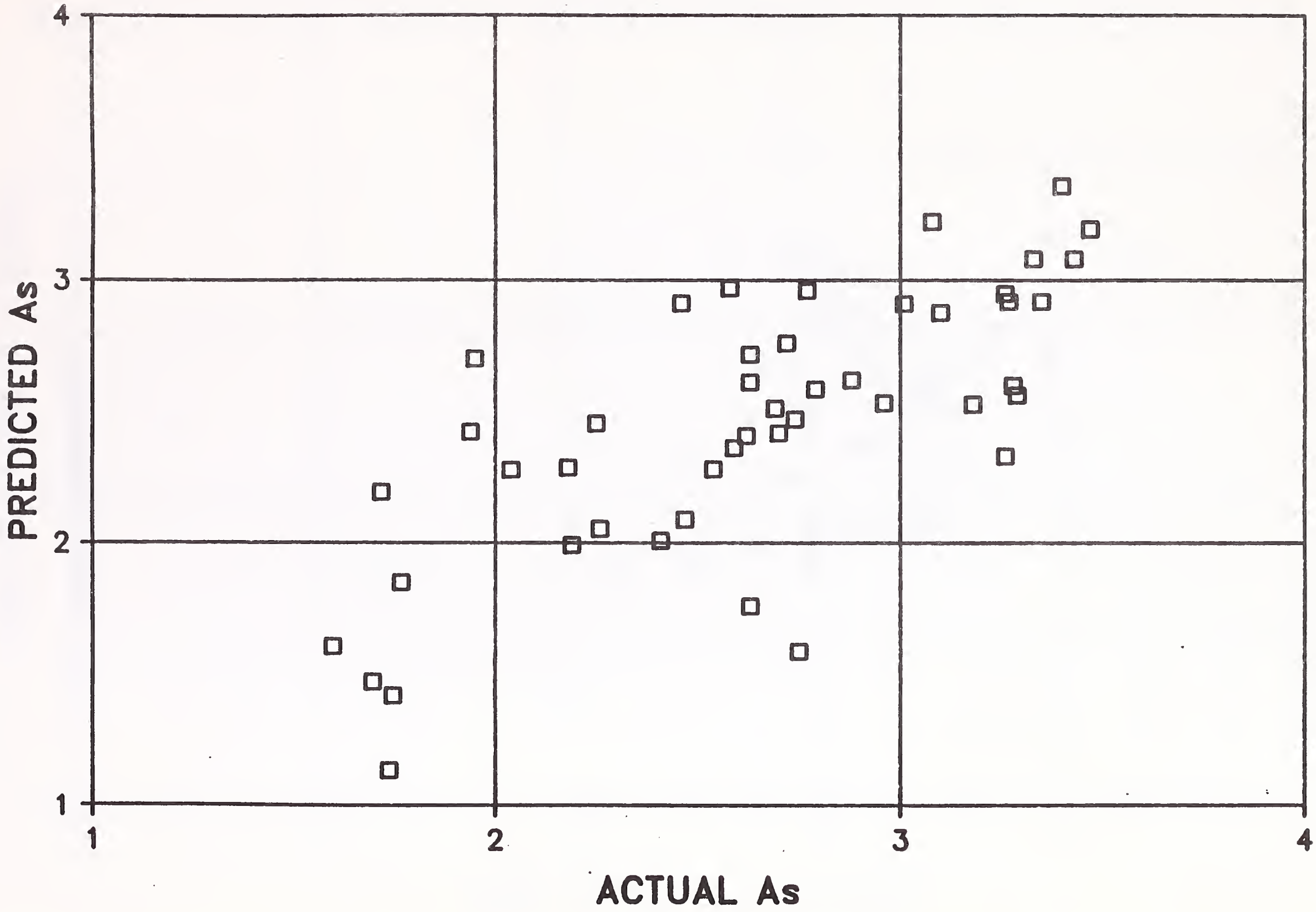
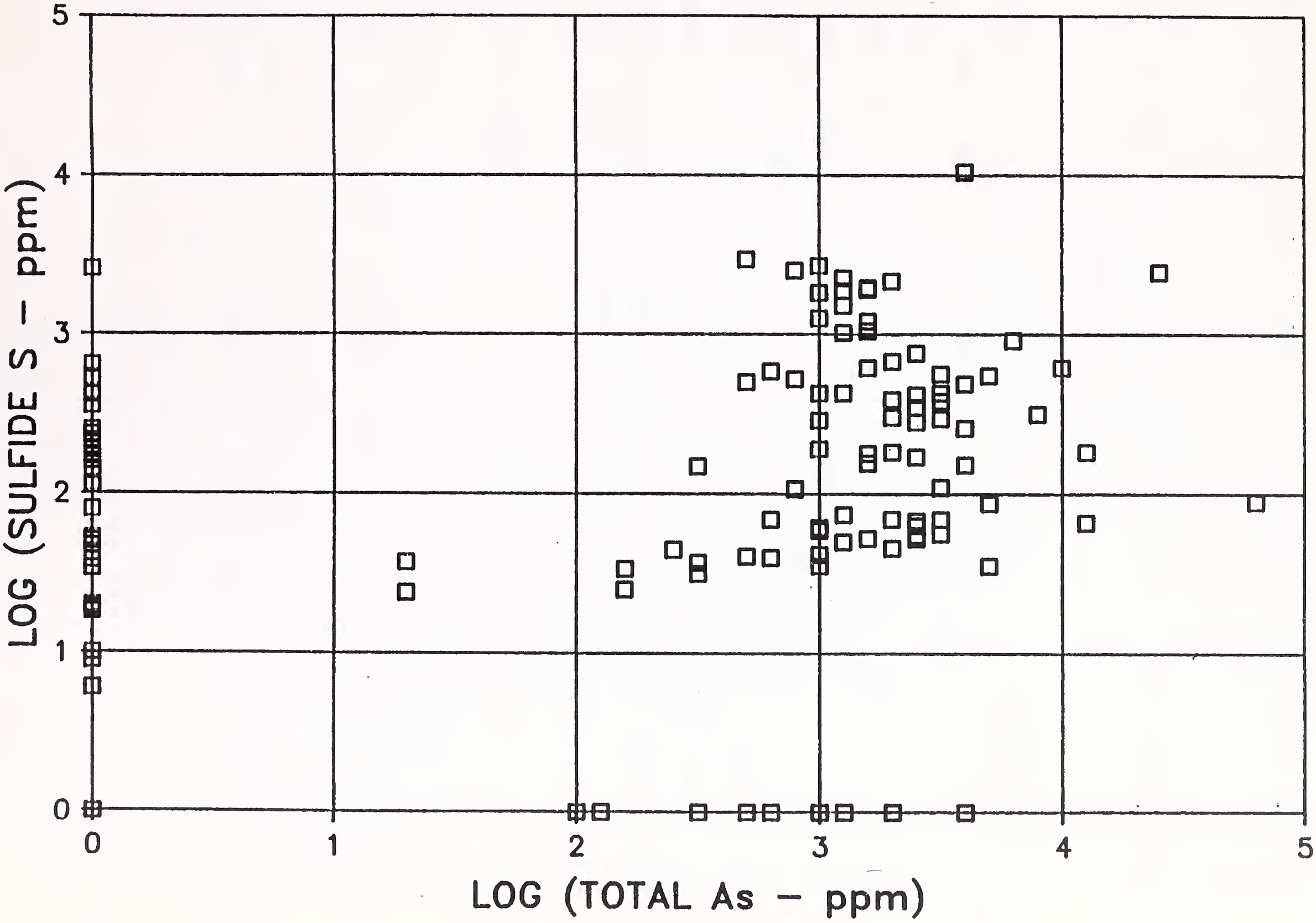


FIGURE 3-15 : PLOT OF TOTAL PYRITE VS. TOTAL ARSENIC : SILVER BOW CREEK RI.



arsenic alone showed little relationship to pH. The total and extractable data available do not clarify the mobility of potential for ground-water contamination and bioaccumulation from arsenic in the tailings. The relative amount of arsenite and arsenate would help clarify this issue.

Comparison of total arsenic in buried soils to soil depth below the tailings (Figure 3-16) does not allow a clear determination of the extent of arsenic movement. The wide variance in geochemical background levels complicates this interpretation. Elevated Halvorson arsenic levels as deep as 25 inches below the tailings indicate arsenic movement has occurred to at least this depth. This observation also suggests that arsenite (the more mobile arsenic form) exists in the tailings and soils on the site. Since arsenic has travelled deeply into the underlying soil, a fairly high potential exists for arsenic movement into ground water.

3.3.1.4 Copper

As expected, soluble copper was inversely correlated with pH ($r = -.59$). A multiple regression model to predict soluble copper was constructed using reverse step-wise multiple linear regression. Independent variables initially assigned to the model included pH, SC, sand, saturation percentage, soluble iron, total copper, pyritic S, sulfate, soil color value, and soil chroma. The model developed was highly significant (Figure 3-17).

FIGURE 3-16 : PLOT OF TOTAL ARSENIC VS. DEPTH BELOW TAILINGS ; SILVER BOW CREEK RI.

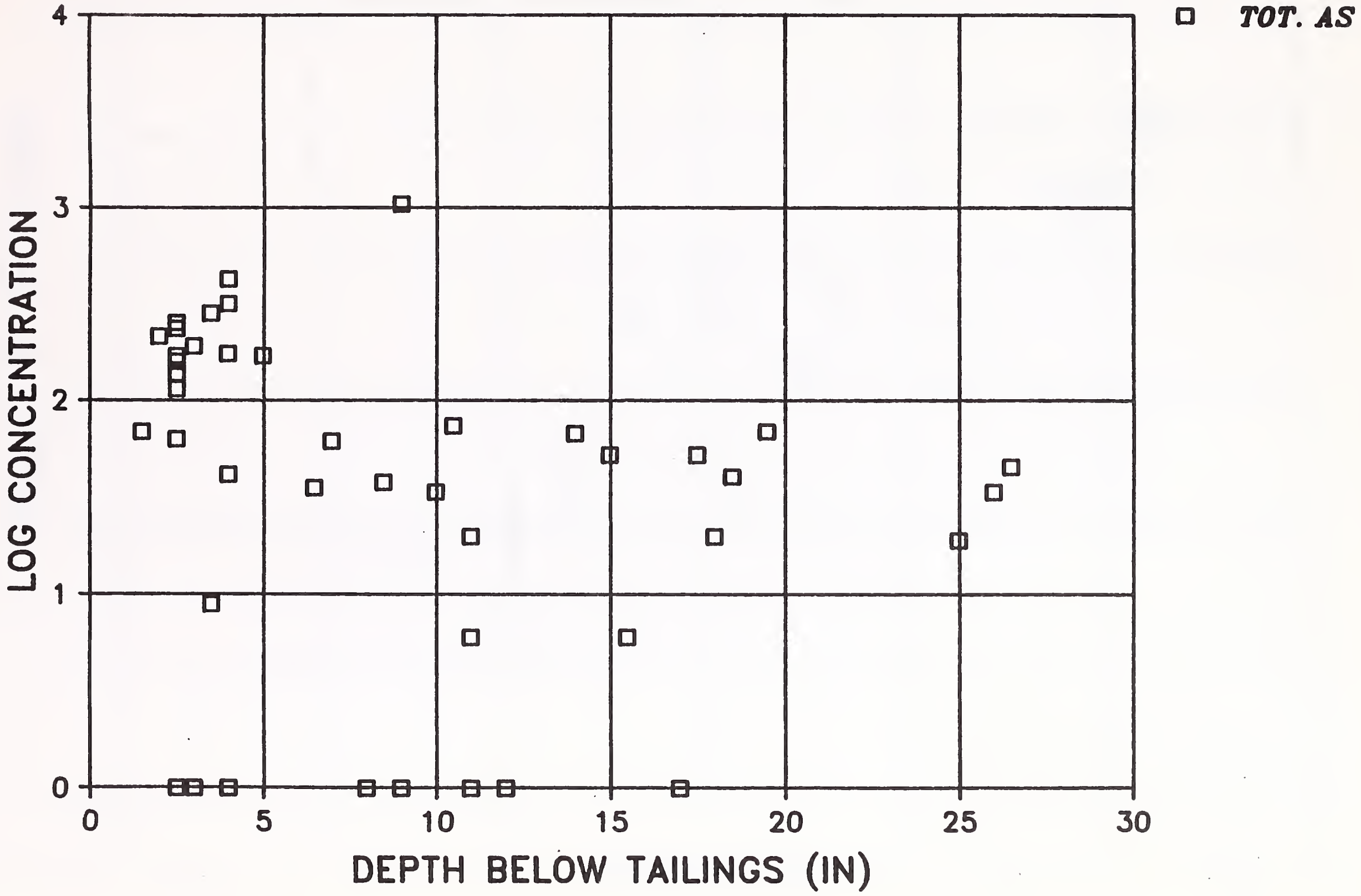
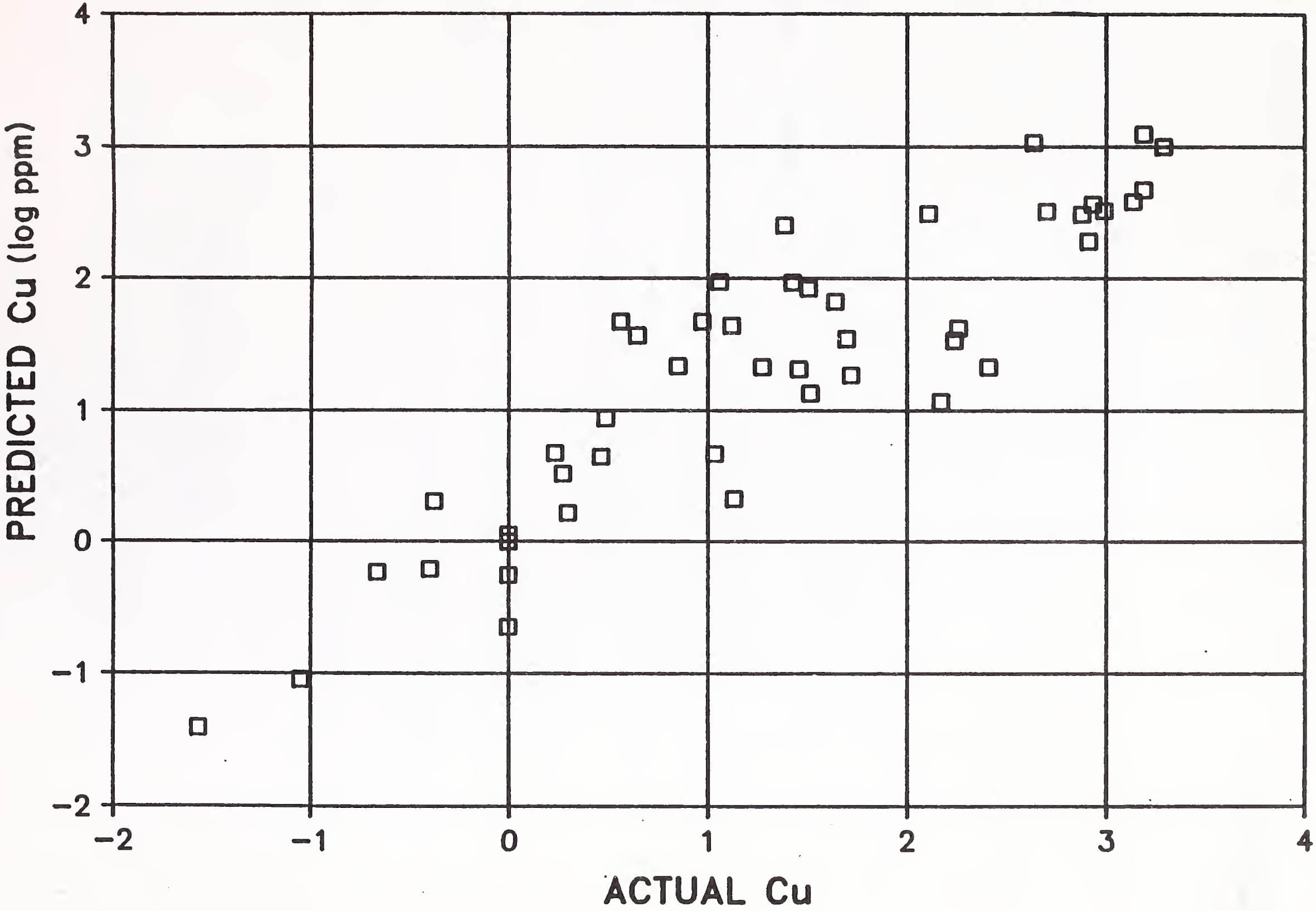


FIGURE 3-17 : SOLUBLE COPPER MLR MODEL ; SILVER BOW CREEK RI.



$$\log(Cu) = 0.926 - .508(pH) + .000081\ (SC) - .239(Fe\text{-}sat) + 0.672\ (SO_4)$$

$$R^2 = 0.81$$

The close relationship to other chemical parameters suggest the possibility of a solid phase mineral controlling copper solubility. To ascertain which, if any, solid phase minerals may have copper solubilities similar to the tailings samples, concentrations were converted to activities and plotted against pH. Stability of various copper minerals was then calculated from published thermodynamic data (Lindsay 1979) and plotted against copper activity. Copper concentration on a soil weight basis was converted to a soil solution molar concentration by using the saturation percentage as an approximation of water content at saturation and then multiplying by atomic weight. Concentrations were corrected to activities using the extended Debye-Huckel coefficient.

$$DH = \text{activity/molarity}$$

Where:

DH is the Debye-Huckel coefficient and is less than 1.

$$\log(DH) = -A\ Z^2\ (m^{0.5}/(1 + B * D * m^{0.5})$$

Where:

A = .509
Z = ion valence (2 for most metals)
m = ionic strength of solution
m can be approximated from the SC
$m = .013 * SC$ (micromhos/cm)
$B = .328 * 10^8$
D = hydrated ion radius ($Cu = 6 * 10^{-8}$)

All available data were plotted on the copper stability diagram (Figure 3-18). All samples from tailings, buried soils, surface salts, or geologic materials fell along two trend lines corresponding roughly to the solubility of malachite ($Cu_2(OH)_2CO_3$) and azurite ($Cu_3(OH)_2(CO_3)_2$) at pH above 5, and corresponding to cupric ferrite ($CuFe_2O_4$) below pH 5. The stability line for cupric ferrite is determined by the equation:

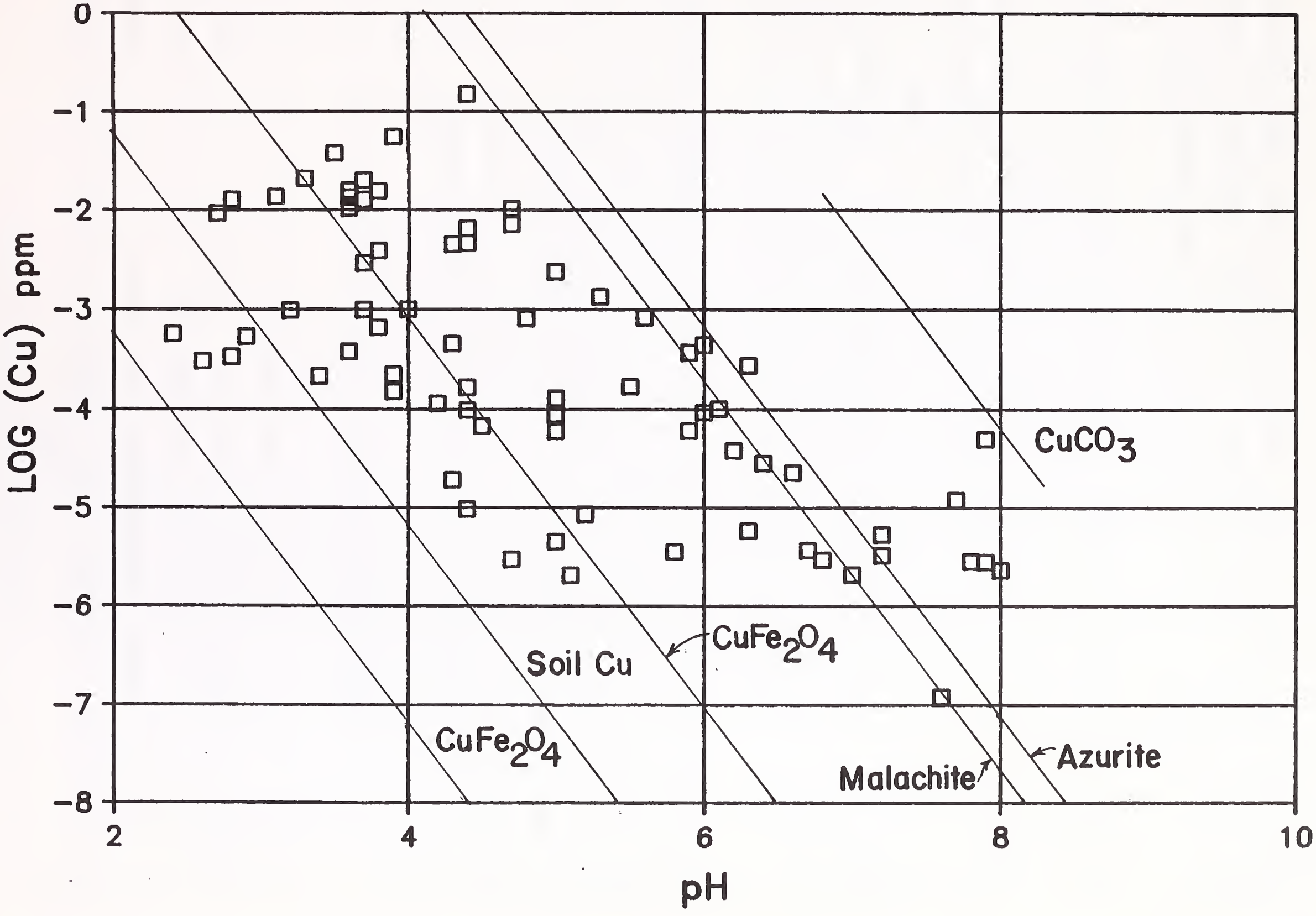
$$CuFe_2O_4 + 2H^+ + 2H_2O = 2(Fe(OH)_3) + Cu^{+2}$$

The solubility of iron in soil was calculated from data for typical soil $Fe(OH)_3$ where log (Fe) = 2.7 - 3pH.

All samples had soluble copper values higher than published values for typical soil copper (Lindsay 1979). Below a pH of 4, copper solubility appeared to decrease below that of cupric ferrite and remained fairly constant at a log copper activity of 10^{-2}. This decrease in copper solubility corresponded to an increase in soluble iron above values normally expected below pH 4. Since cupric ferrite contains both ferric iron and cupric copper, increasing ferric iron would tend to depress copper solubility. A second stability line for cupric ferrite corresponding to the higher solubility seen in tailings indicates a possible lower limit of copper solubility at low pH.

Use of stability data to predict copper solubility may be useful in the feasibility study. If, for example, it were found that 2 ppm

FIGURE 3-18 : PLOT OF COPPER ACTIVITY VS. pH : SILVER BOW CREEK RI.



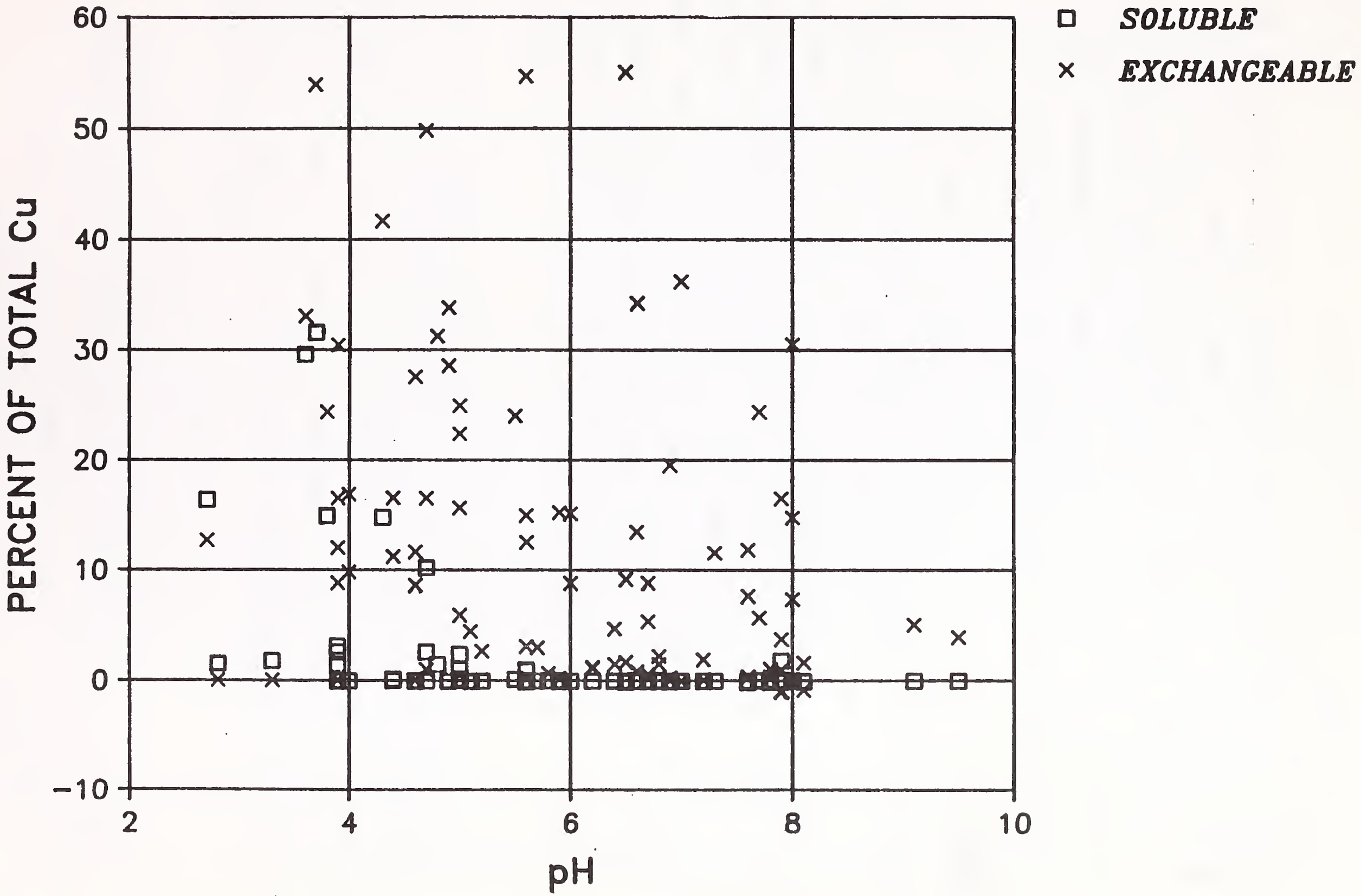
soluble copper were the acceptable level in soil and that at pH above 5 malachite controlled solubility, then the target pH for lime application could be calculated.

By comparing the fraction of total copper to soluble and ammonium acetate extractable forms, conclusions can be drawn about relative mobility and availability at various pH levels. The saturation extractable fraction of total copper can readily leach from soil into suface or ground water and can pose a threat to water quality if excessive. The ammonium acetate extractable copper is the weakly bound (adsorbed) and exchangeable plus soluble copper. This fraction best represents the bioavailable copper in the system.

Tailings represent a significant contaminant source to water quality through leachate mechanisms. The percentage of copper in the water soluble fraction averaged 8% in tailings and less than 0.1% in buried soils. Weakly bound and exchangeable copper (ammonium acetate extractable) averaged 27.1% in tailings and 12.5% in buried soils. Although buried soils do not have significant soluble copper, both tailings and buried soils may allow bioaccumulation of copper due to the excessive levels of readily available copper.

Figure 3-19 illustrates copper partitioning as a function of substrate pH for all samples. The soluble copper fraction was inversely correlated with pH ($r=-0.68$) and was less than 2 to 3% of total copper at pH levels above 4.5. Exchangeable copper fraction was not as well correlated with pH in soil or tailings samples and was

FIGURE 3-19 : COPPER PARTITIONING IN SILVER BOW CREEK RI MATERIAL SAMPLES.



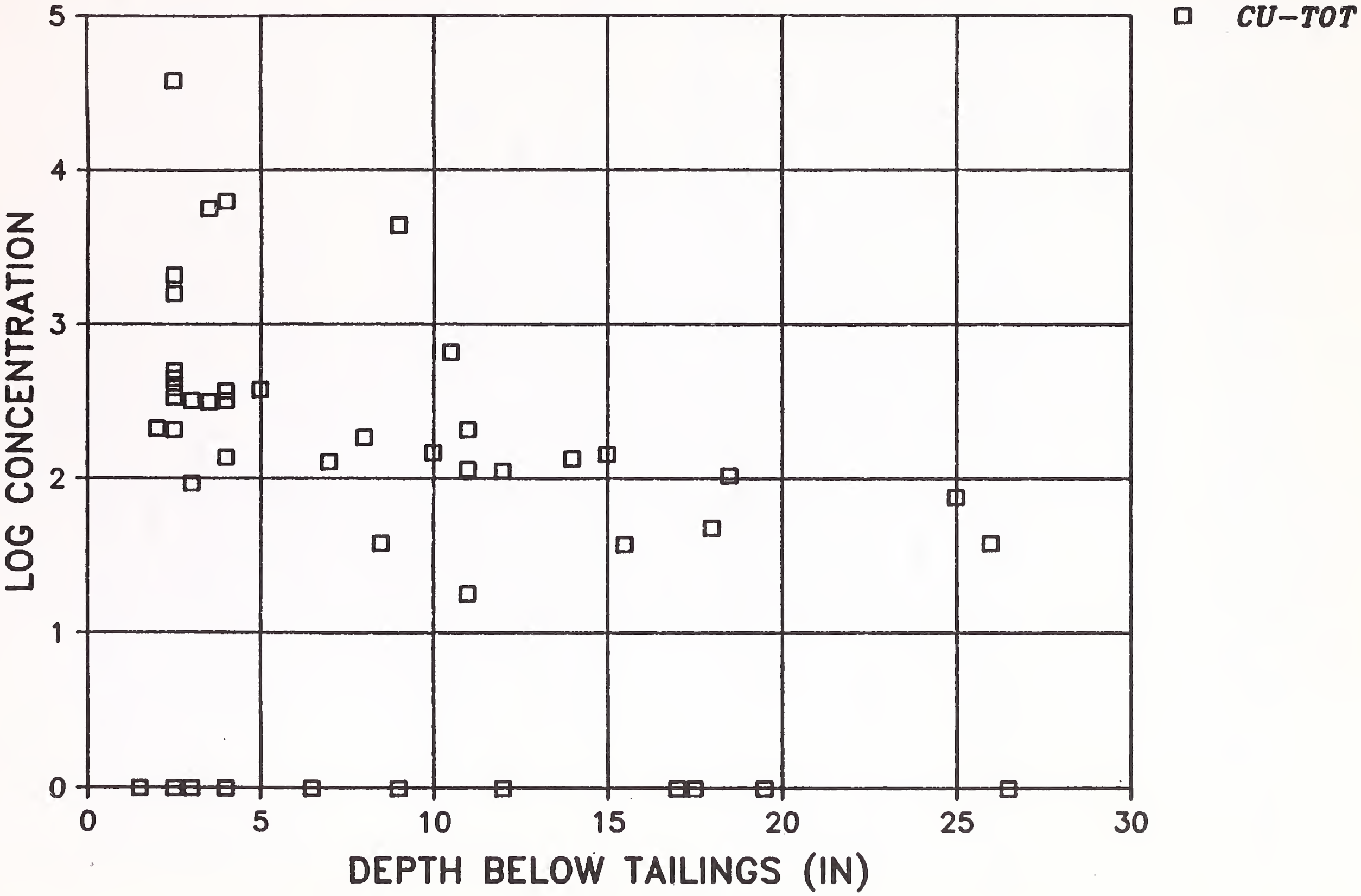
high at all pH levels. Although no data are available on organic matter content, soluble copper fraction and soil color value were correlated (r=.43), meaning that soluble copper was lower as color value decreased (higher organic matter level). This indicates a possible complexing of copper by organic matter. Soil color value did not correlate with the soluble fraction of any other metals.

Migration of copper and other minerals out of tailings into underlying soils is a potential concern. In many locations ground water is located within or just below tailings deposits. Thus, the distribution of metals below the tailings may suggest the tendency for metal flux into ground water. In Site 6 tailings, which are very acid and high in metals, a significant enrichment in soluble copper was seen for 20 or more inches below tailings. Reduced pH or copper movement may account for the increase. A similar increase in soluble copper in buried soil was noted in Site 9 with less acid tailings.

At Site 25 on Ramsay Flats, with moderately acid tailings, total copper (655 µg/g) is noticeably elevated in the 31 to 50 inch zone beginning at the base of the tailings. Total copper below 50 inches (138 µg/g) approaches background levels. Soluble and exchangeable copper also are elevated in the first (31 to 50 inch) layer of buried soil.

In a composite of all soil samples buried by tailings, total copper was plotted as a function of depth below the tailings (Figure 3-20).

FIGURE 3-20 : PLOT OF TOTAL COPPER VS. DEPTH BELOW TAILINGS ; SILVER BOW CREEK RI.



Maximum depth of elevated total copper is about 20 inches site-wide. Water tables are located within 20 inches of the base of the tailings at many locations.

3.3.1.5 Cadmium

Both soluble and exchangeable cadmium levels were well correlated with SC (r=.69, r=.53), and inversely with sand (r=⁻.62, r=-.72), but not with soil pH. Evidence that cadmium was not strongly affected by pH was shown also by the developed stability diagram (Figure 3-21). Limited studies of soil cadmium have shown relatively constant cadmium at 10^{-7}M, with low cadmium addition (Street et al. 1978) and 10^{-4}M in heavily amended soils (Santillan-Medrano and Jurinak 1975).

The percentage of total cadmium in the soluble phase was 11.8% for tailings and 0.49% for buried soils. Exchangeable cadmium was 21.9 and 19.7%, respectively, for tailings and soils. Cadmium may readily leach from tailings to ground water. In addition, both tailings or buried soils may have appreciable bioavailable cadmium (Figure 3-22).

Cadmium appears to have moved well below the tailings at Ramsay Flats into underlying soil; the total and exchangeable cadmium levels in upper soil layers are as high or higher than in tailings. Soluble cadmium was somewhat lower in buried soil than tailings, which may be due to the higher pH, higher exchange capacity, or

FIGURE 3-21 : PLOT OF CADMIUM ACTIVITY VS. pH ; SILVER BOW CREEK RI.

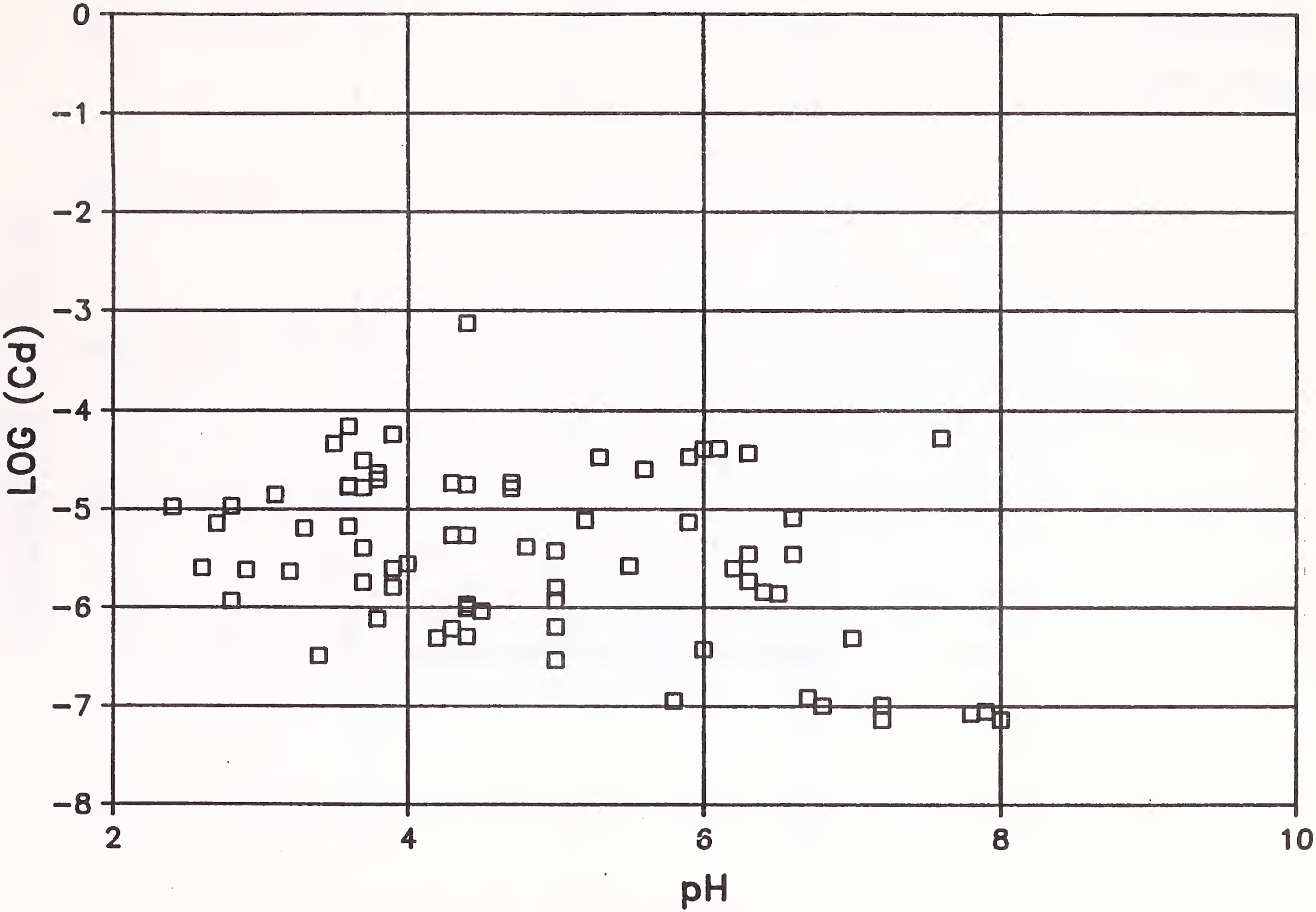
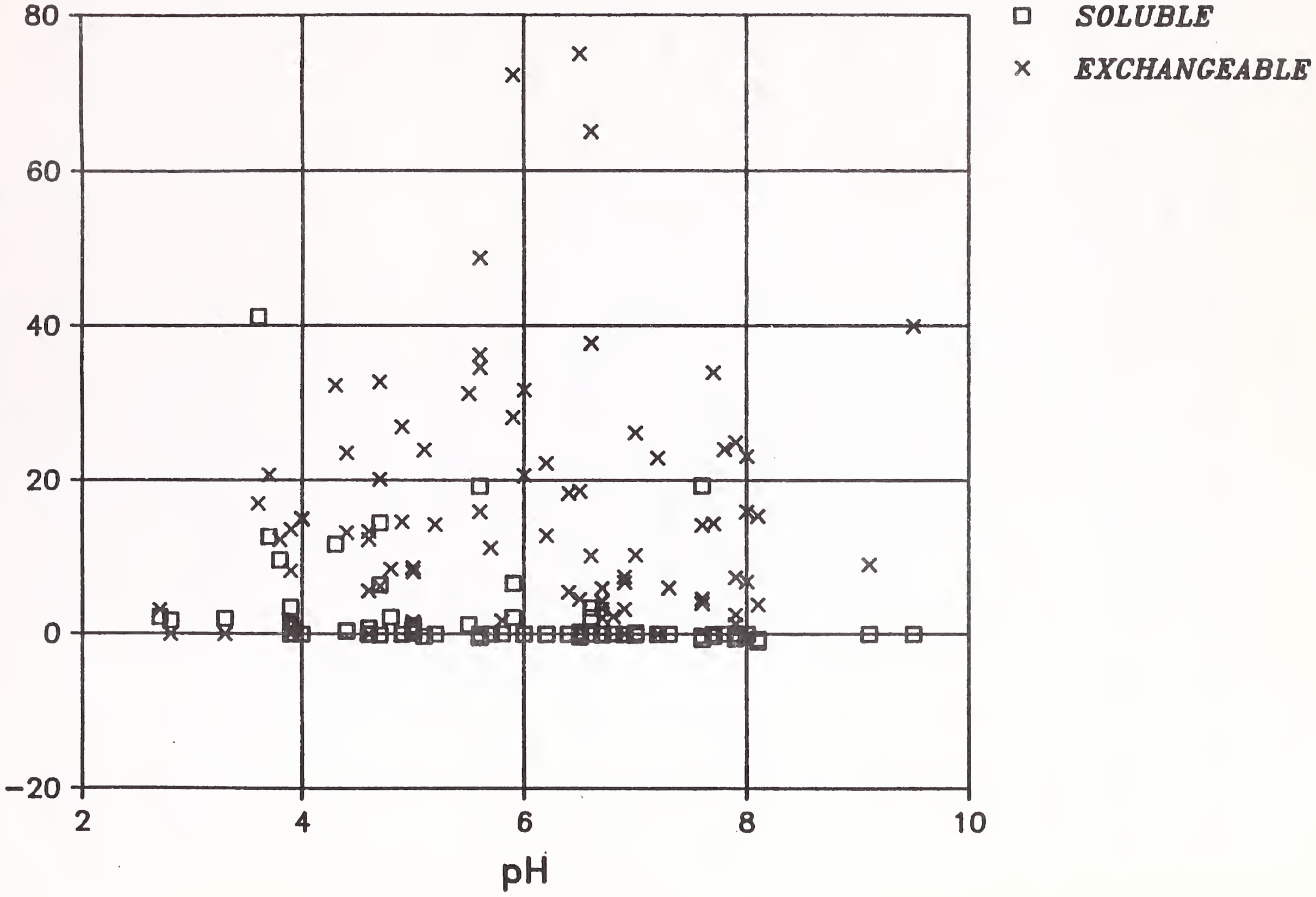


FIGURE 3-22 : CADMIUM PARTITIONING IN MATERIAL SAMPLES ; SILVER BOW CREEK RI.



higher organic matter content of the soil. Cadmium in buried soils appears to be elevated strongly (enrichment greater than ten-fold) to 15 inches deep and is slightly elevated to at least a depth of 30 inches (Figure 3-23).

3.3.1.6 Iron

A stability diagram of iron minerals was constructed to compare to iron solubility in tailings and soil materials (Figure 3-24). Soil $Fe(OH)_3$ was plotted, assuming all soluble iron was ferric. This line, as well as the solubility of jarosite ($KFe_3(SO_4)_2(OH)_6$), is well below the solubility actually observed. This suggests that the ferrous ion may be important in this system, which in turn suggests that weakly oxidizing conditions prevail in the samples (Eh about 50 to 150 mv). Lines for solubility of ferrous iron in equilibrium with soil $Fe(OH)_3$ at pH + pe of 11.6 are shown also. At pH below 4 to 5, jarosite would control ferrous iron solubility and would in turn be influenced by sulfate concentration.

The relationships governing iron solubility are complex, but it is clear that ferrous ion dominates the iron system and that the system has weakly oxidizing conditions. The elevated iron levels may have a depressing effect on copper and zinc solubility with which iron forms solubility-limiting oxides (cupric ferrite, franklinite).

The fraction of iron in the soluble form is low in both tailings and soils, indicating little tendency for iron to be mobilized.

FIGURE 3-23 : PLOT OF TOTAL CADMIUM VS. DEPTH BELOW TAILINGS ; SILVER BOW CREEK RI.

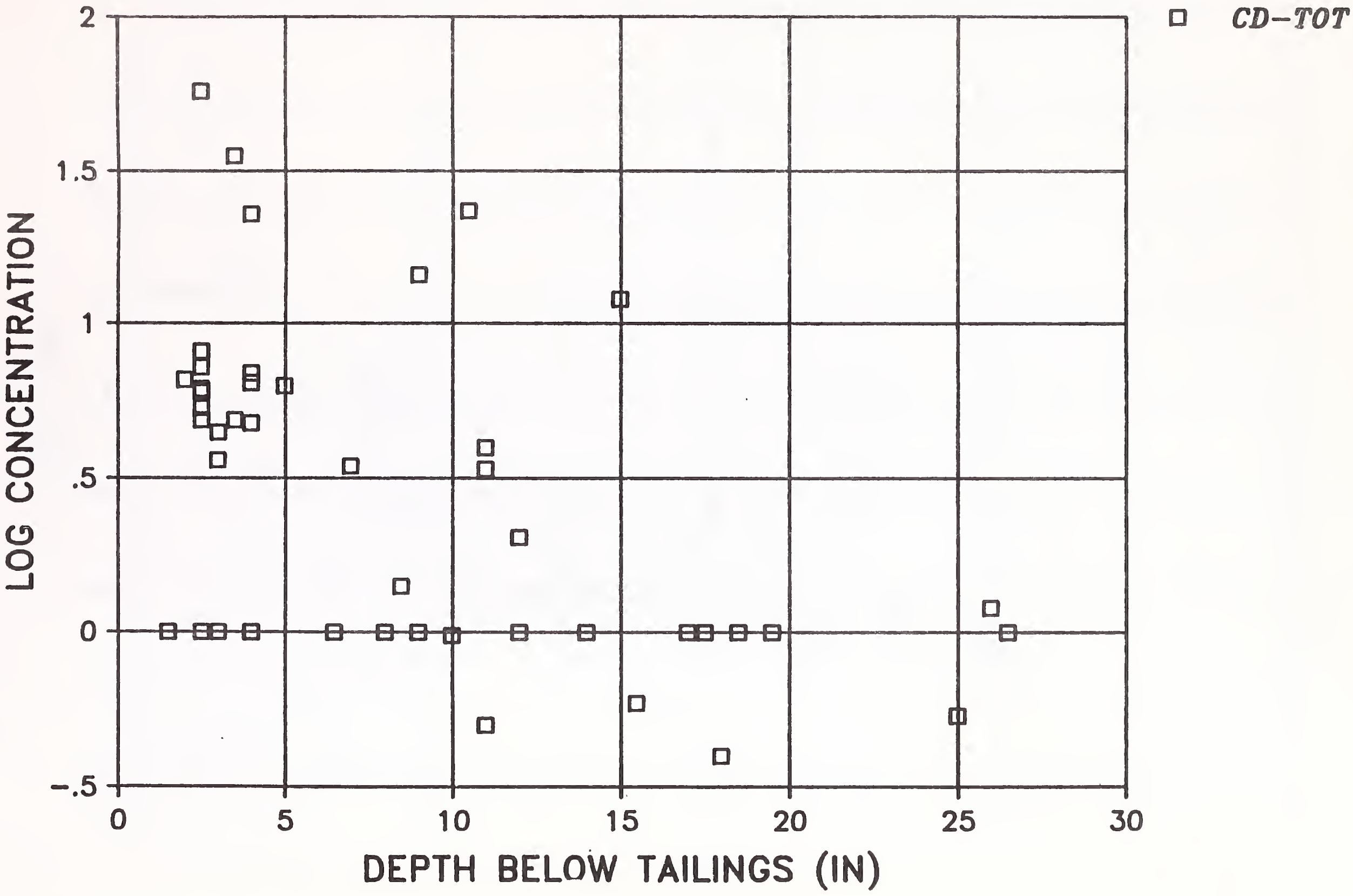
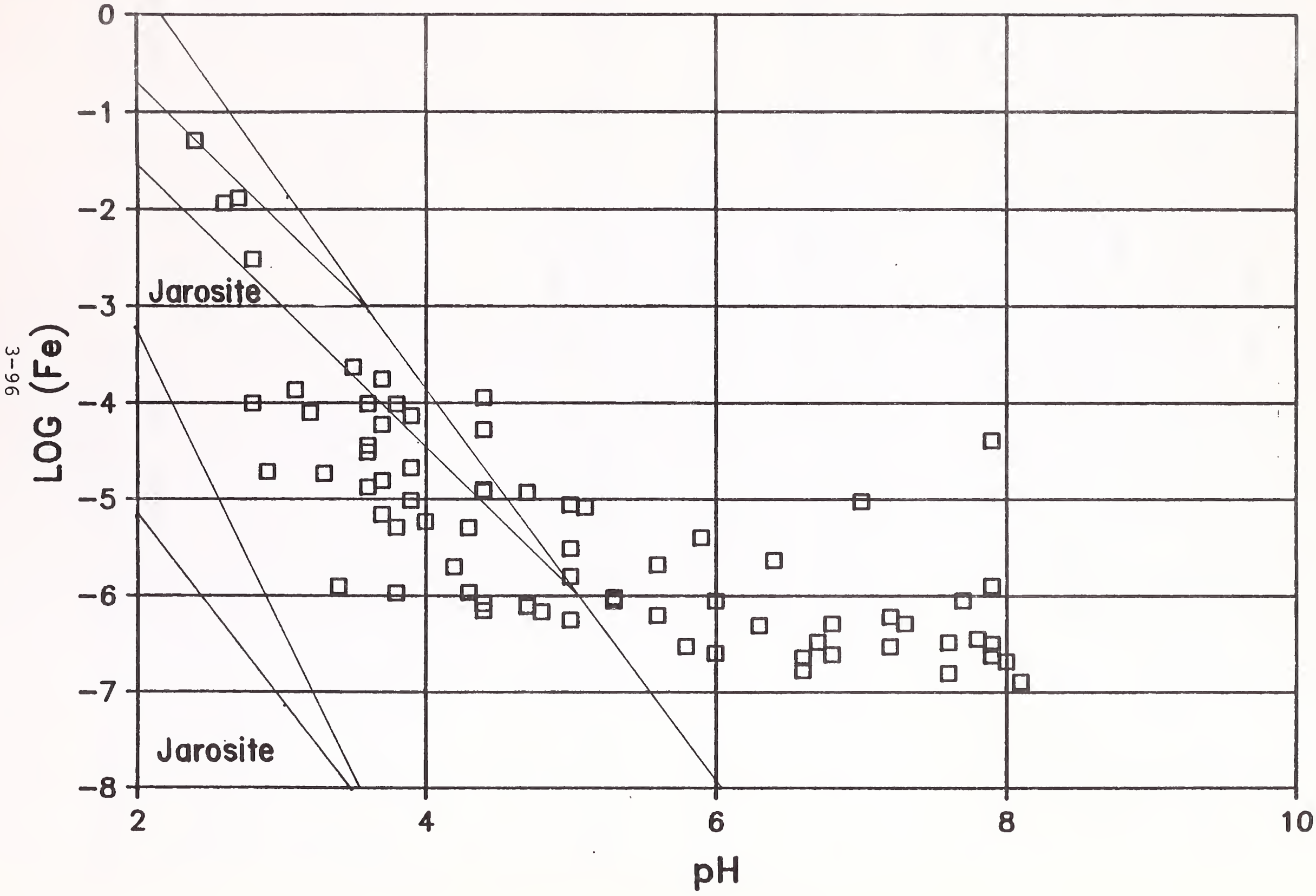


FIGURE 3-24 : PLOT OF IRON ACTIVITY VS. pH : SILVER BOW CREEK RI.



Localized low redox conditions (which would not be maintained in a laboratory setting) may elevate soluble iron far above that found by analyzing samples in oxidizing conditions. Exchangeable iron averages 12.1% in tailings and less than 0.1% in soils. Formation of a somewhat soluble iron compound (like jarosite) may account for the higher exchangeable fraction in tailings. Bright yellow soil colors (2.5 Y 6/7), typical of jarosite, were observed in many tailings.

The exchangeable iron level was also predicted by a multiple linear regression model (Figure 3-25).

$$\log(\text{Fe-exch}) = 1.781 - .353(\text{pH}) + .0000669\ (\text{SC}) + .16\ (\text{value})$$
$$R^2 = 0.69$$

Inclusion of soil color value in the model may indicate the formation of humic-iron complexes, increasing the retention of iron.

3.3.1.7 Lead

Few variables correlated well with saturation extractable lead content. Exchangeable lead increased with increasing soil pH (r=.50). The stability diagram for lead in tailings (Figure 3-26) showed little change in solubility with increasing pH. Lead activity remained constant near 10^{-5} to 10^{-6} M. The stability of $PbSO_4$ corresponds to $10^{-5.5}$ at a sulfate concentration of $10^{-2.4}$ M, the average for all samples. Lead solubility appears to follow $PbSO_4$

FIGURE 3-25 : EXCHANGEABLE IRON MODEL : SILVER BOW CREEK RI.

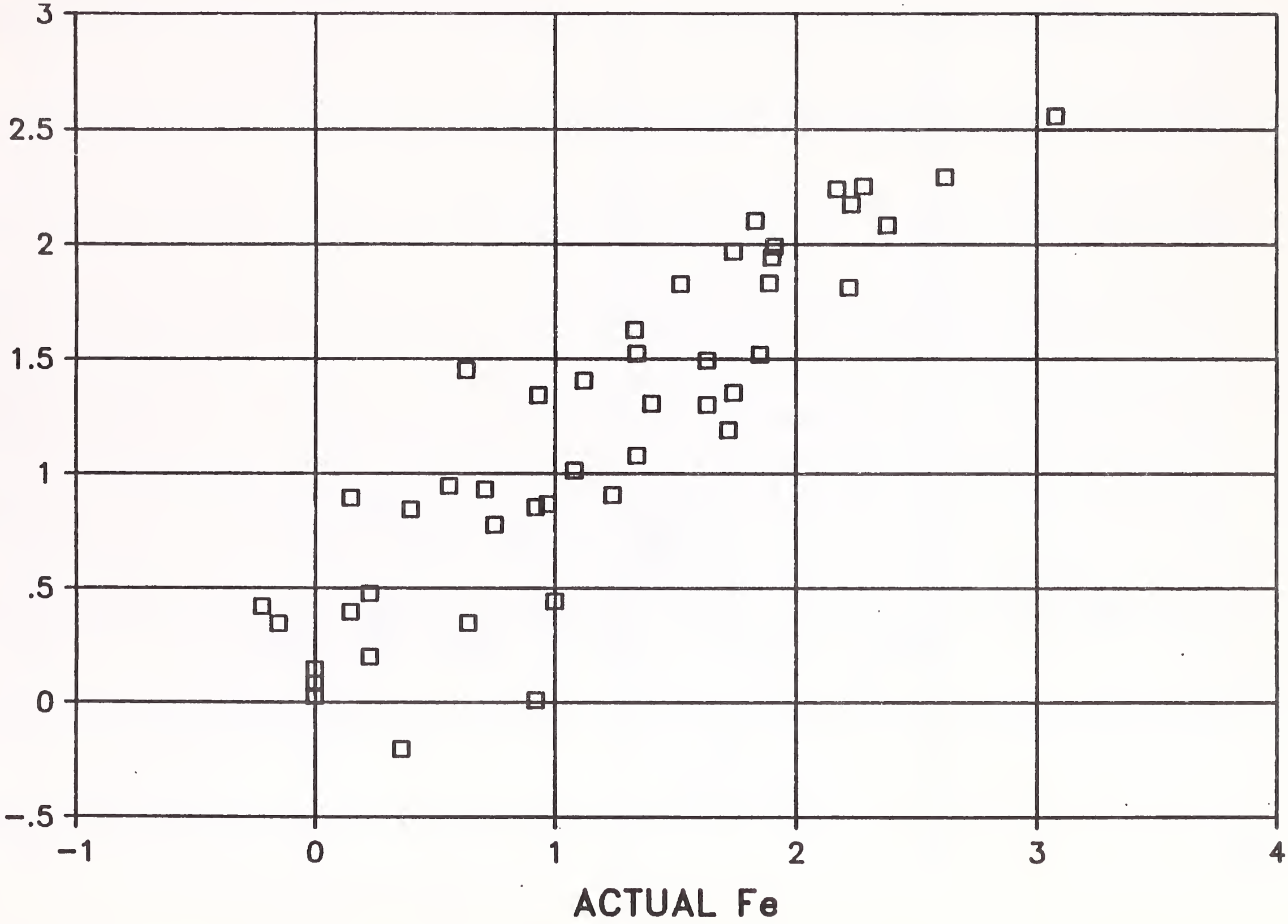
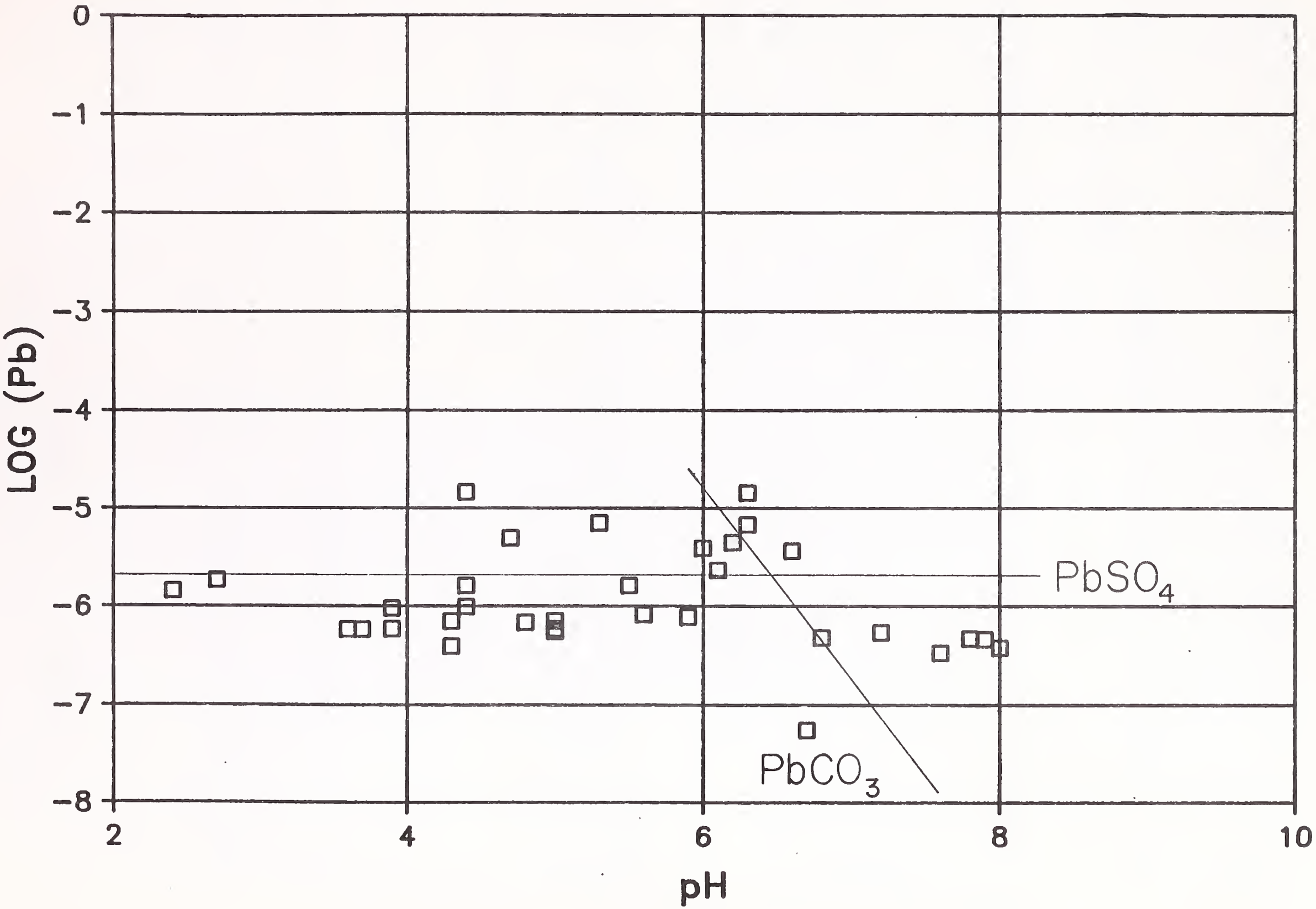


FIGURE 3-26 : PLOT OF LEAD ACTIVITY VS. pH : SILVER BOW CREEK RI.



solubility above pH 6, despite the lower solubility of cerrusite ($PbCO_3$) and a variety of other phosphates, carbonates, and oxides of lead. Due to the low solubility of lead sulfate, lead is of less concern as a ground-water contaminant than copper, zinc, arsenic, or cadmium.

Partitioning of lead into soluble and exchangeable components is illustrated in Figure 3-27. Soluble lead is a minute portion of total lead at all pH levels. Exchangeable lead appears to increase at higher pH and ranges from 2 to as high as 40% of total lead. Exchangeable lead averaged 6.0 and 9.3% in tailings and soils, respectively. Lead is therefore unlikely to constitute a threat to ground water or surface water due to limited solubility.

Lead appears to be less mobile than other metals investigated. Total lead usually was elevated only in the top 2 inches of buried soil (Figure 3-28), with elevated lead noted at 10 inches in only two samples of buried soil.

3.3.1.8 Manganese

Soluble manganese was inversely correlated with pH ($r=-.35$) and sand ($r=-.40$) and increased with increasing SC ($r=.69$). A multiple linear regression model to predict soluble manganese was developed (Figure 3-29) with pH, SC, sand, saturation percentage, and sulfate as independent variables.

FIGURE 3-27 : LEAD PARTITIONING IN SILVER BOW CREEK RI MATERIAL SAMPLES.

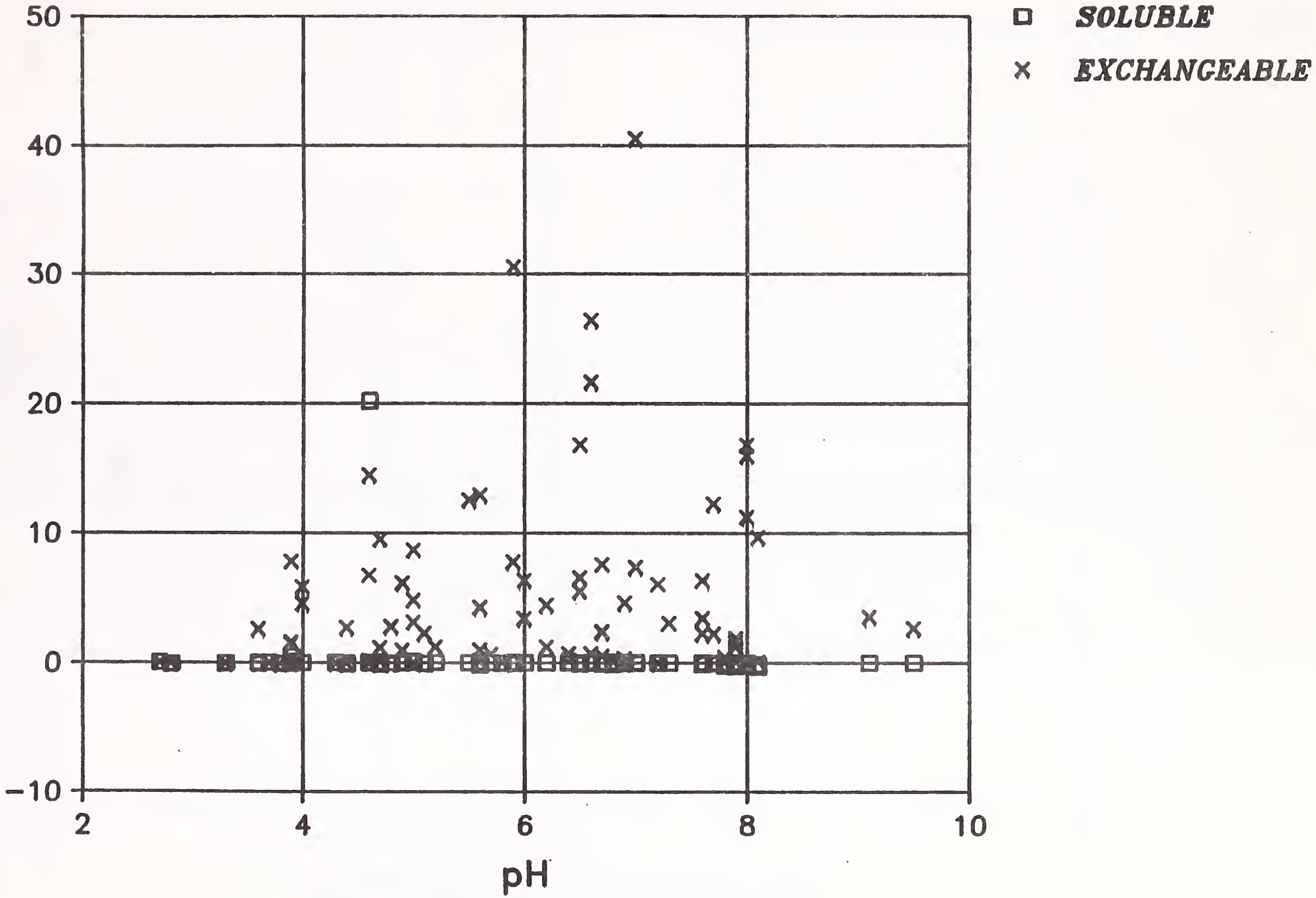


FIGURE 3-28 : PLOT OF TOTAL LEAD CONCENTRATIONS VS. DEPTH ; SILVER BOW CREEK RI.

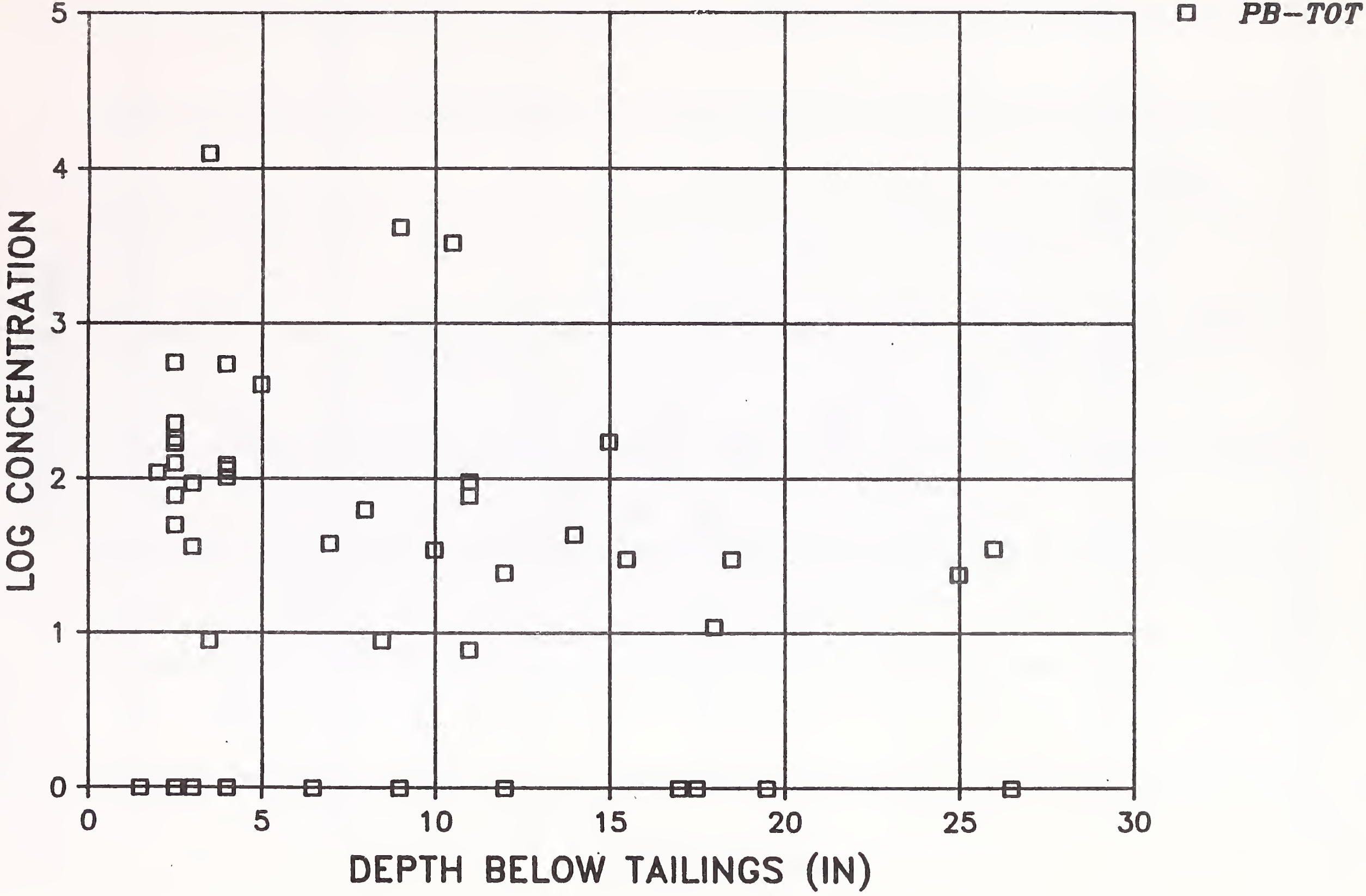
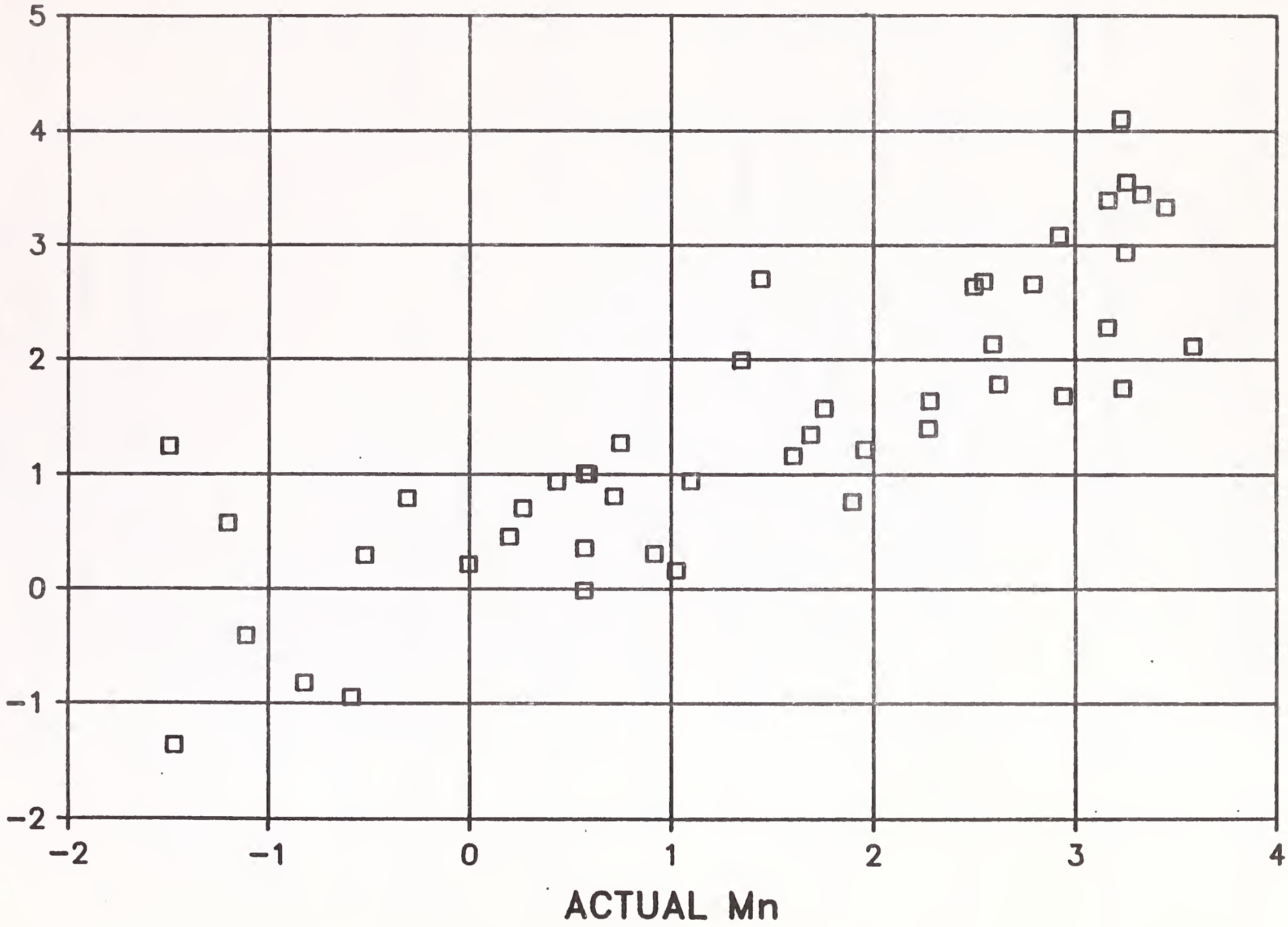


FIGURE 3-29 : SOLUBLE MANGANESE MLR MODEL ; SILVER BOW CREEK RI.



$$\log(\text{Mn-sat}) = 4.152 - 2.64\ (\text{pH}) + .000109(\text{SC}) - .0361(\text{sand}) - .0484(\text{sat'n}) + .575(SO_4)$$

$$R^2 = 0.71$$

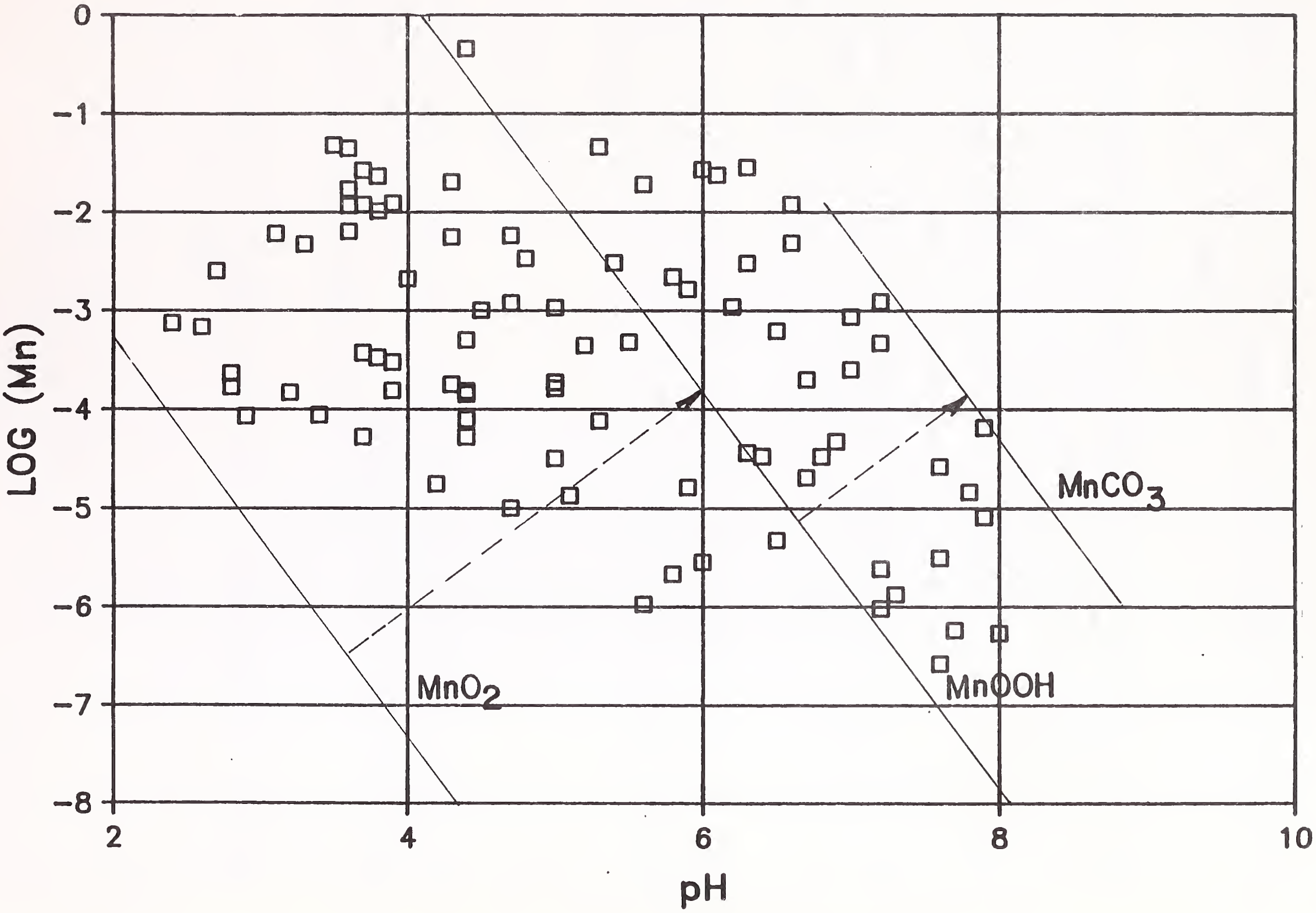
The fit to the regression model appeared best at higher manganese levels.

A stability diagram of solubility manganese (Figure 3-30) indicates that factors other than pH control solubility. Manganese is known to be strongly affected by redox potential; three valence states (Mn^{+4}, Mn^{+3}, Mn^{+2}) are found in soil environments. Manganese solubility appears to be controlled by either pyrolusite (MnO_2) or manganite (MnOOH), depending on the redox potential of the system.

In soil systems, Mn^{+4} is dominant, with a pH + pe of greater than 16.6. When the redox potential is lower, Mn^{+3} becomes dominant. The likely range of pH + pe in these soils, judging from manganese solubility, is 14.5 to 18.5. Redox measurements of 0 to 100 mv (pH + pe = 7 to 9) suggest lower Eh levels exist in the tailings and buried soils. Thus, changes in the equilibrium Eh after samples were collected may have affected the measured manganese solubility.

If pH + pe levels were as low as 10, then rhodochrosite ($MnOSiO_3$) would likely control solubility, and soluble manganese would be 1.0 M at a pH of 4 or less. Thus, the potential for manganese contamination of ground water would be very high if redox potential was low in the system. Presence of near-saturated conditions, presence of organic matter in buried soil, low redox potential

FIGURE 3-30 : PLOT OF MANGANESE ACTIVITY VS. pH : SILVER BOW CREEK RI.



measurements, and elevated iron in suction lysimeter samples all suggest that redox is low enough in some tailings and buried soils to cause elevated manganese.

Soluble manganese accounted for 22.8% of total manganese in tailings, but only 0.40% in buried soils. Exchangeable manganese was 33.6 and 6% in tailings and soils, respectively. The abundance of soluble manganese and elevated total manganese content both suggest leaching of manganese from tailings is likely and the possibility of manganese toxicity in vegetation grown on these materials. The elevated soluble and exchangeable fractions of manganese occur mostly below pH of 6 (Figure 3-31).

No assessment of manganese movement into buried soils was made because of high background levels of manganese and limited manganese enrichment.

3.3.1.9 Zinc

Soluble zinc was inversely correlated with pH (r=-.41) and was also correlated with SC (r=.66). A multiple regression model to predict soluble zinc was assembled (Figure 3-32).

$$\log(Znsat) = 2.585 - .505(pH) - .0131(sand) + .744(SO_4) - .107(chroma)$$
$$R^2 = 0.69$$

FIGURE 3-31 : MANGANESE PARTITIONING IN SILVER BOW CREEK RI MATERIAL SAMPLES

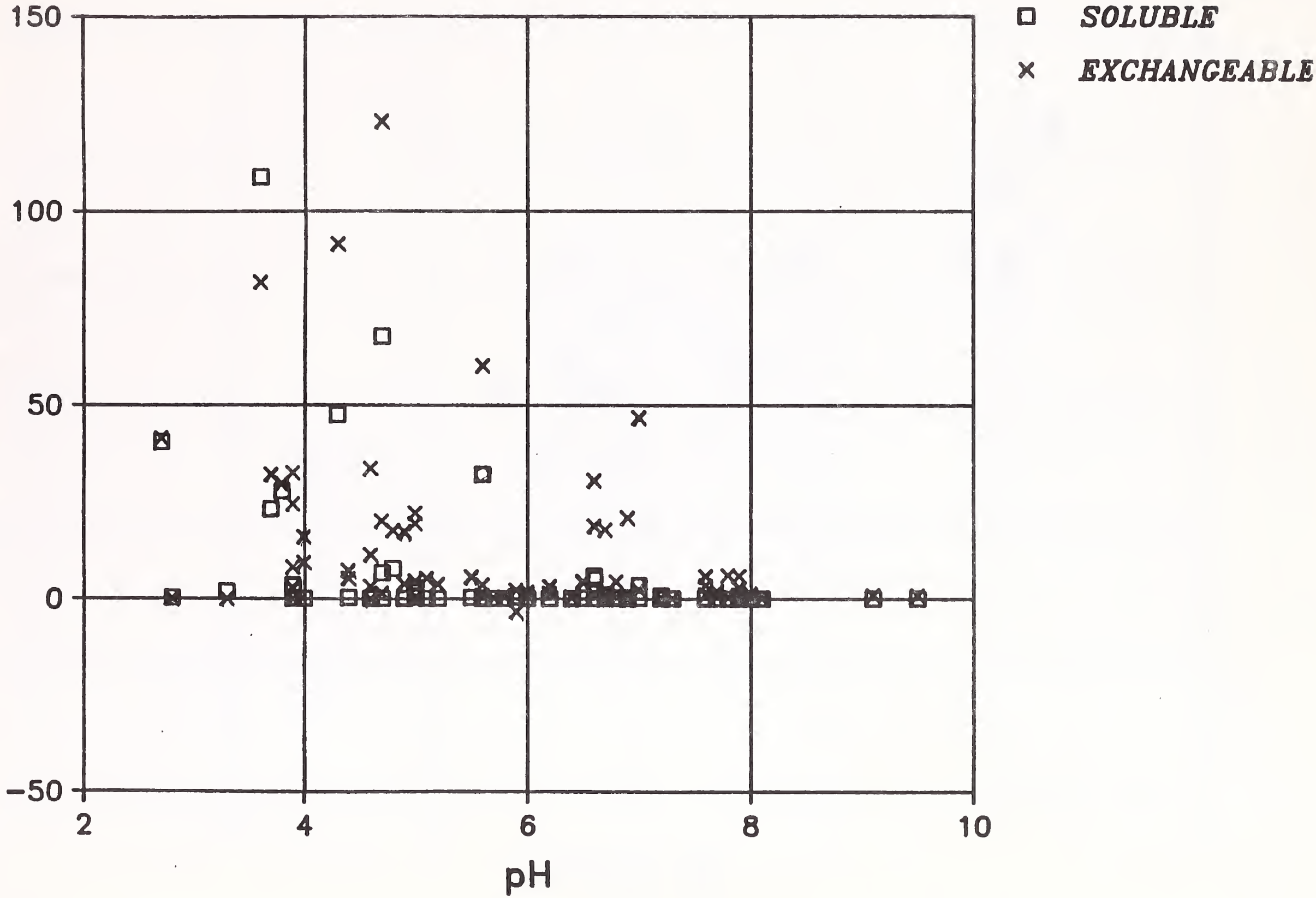
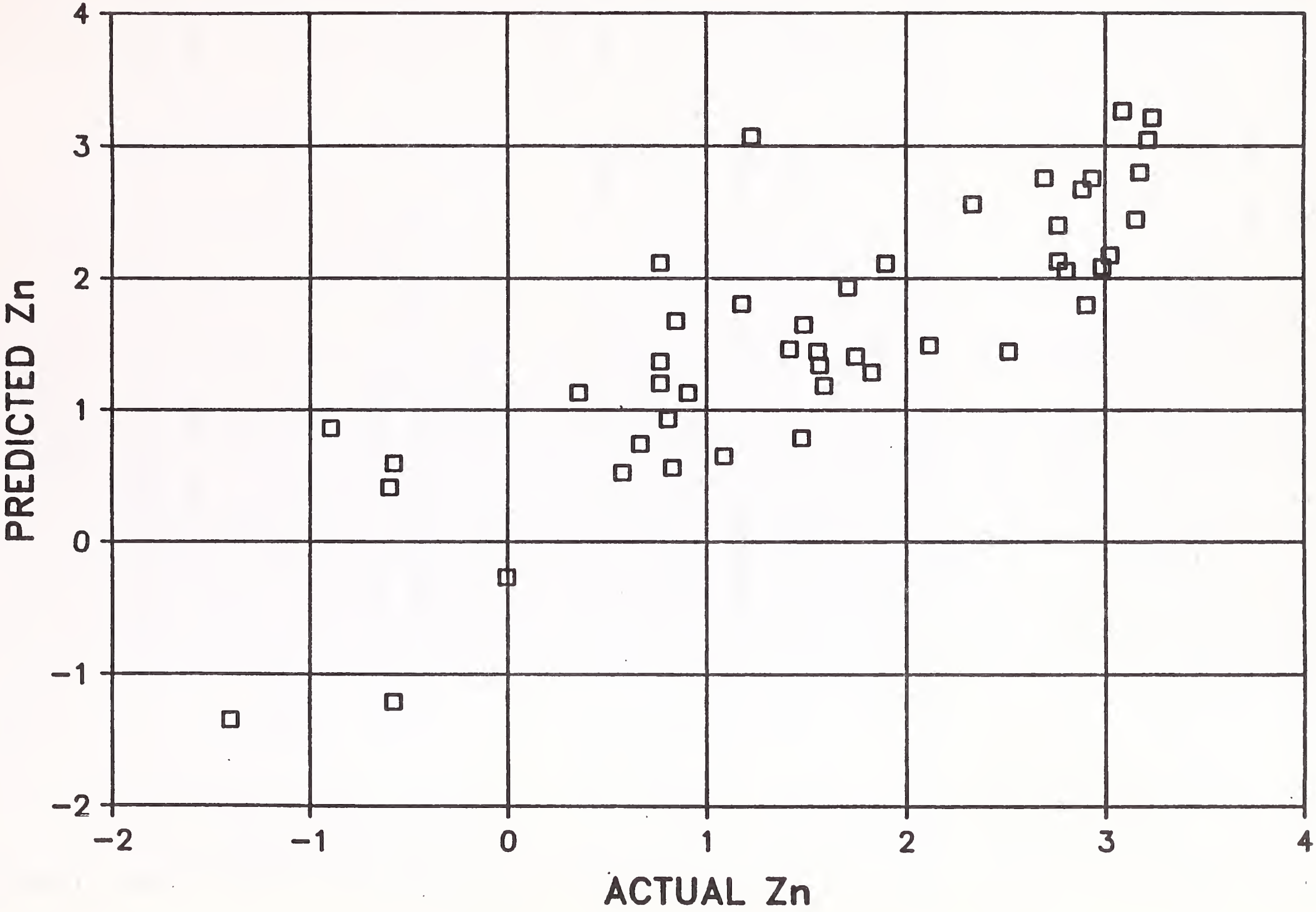


FIGURE 3-32 : SOLUBLE ZINC MLR MODEL :
SILVER BOW CREEK RI.



As expected, soluble zinc increases with decreasing pH. Zinc is lower at higher sand content, probably due to leaching of zinc from sandy materials. Increases in zinc with increasing sulfate may indicate that zinc is related to the amount of past pyrite oxidation, of which sulfate is an indicator. The effect of soil color chroma is to increase zinc at low chroma, an indicator of reducing conditions.

The stability diagram for zinc (Figure 3-33) is fairly similar to that for copper. At pH below 5, soluble zinc activity corresponds to typical values for soil zinc (Lindsay 1979) and for Franklinite ($ZnFe_2O_4$). Below a pH of 3.5, zinc solubility drops below the stability of Franklinite, which may be explained by elevated soluble iron at these pH levels. Thus at low pH, soluble iron may limit zinc solubility as it may for copper. At pH above 5 it appears that Willemite (Zn_2SiO_4) or Smithsonite ($ZnCO_3$) may best explain zinc solubility.

Soluble zinc comprises 6.8 and 0.27% of total zinc in tailings and buried soils, respectively, while exchangeable zinc is 14.8 and 17.1% in tailings and soils. Soluble zinc comprises a large fraction of total zinc mostly below a pH of 6 (Figure 3-34), while exchangeable zinc is significant at pH levels up to 7.5. Comparison of total zinc in buried soil to depth below the tailings (Figure 3-35) indicates that zinc enrichment has occurred up to 15 inches into the soils. Zinc is thus similar to copper in chemistry and mobility.

FIGURE 3-33 : PLOT OF ZINC ACTIVITY VS. pH ; SILVER BOW CREEK RI.

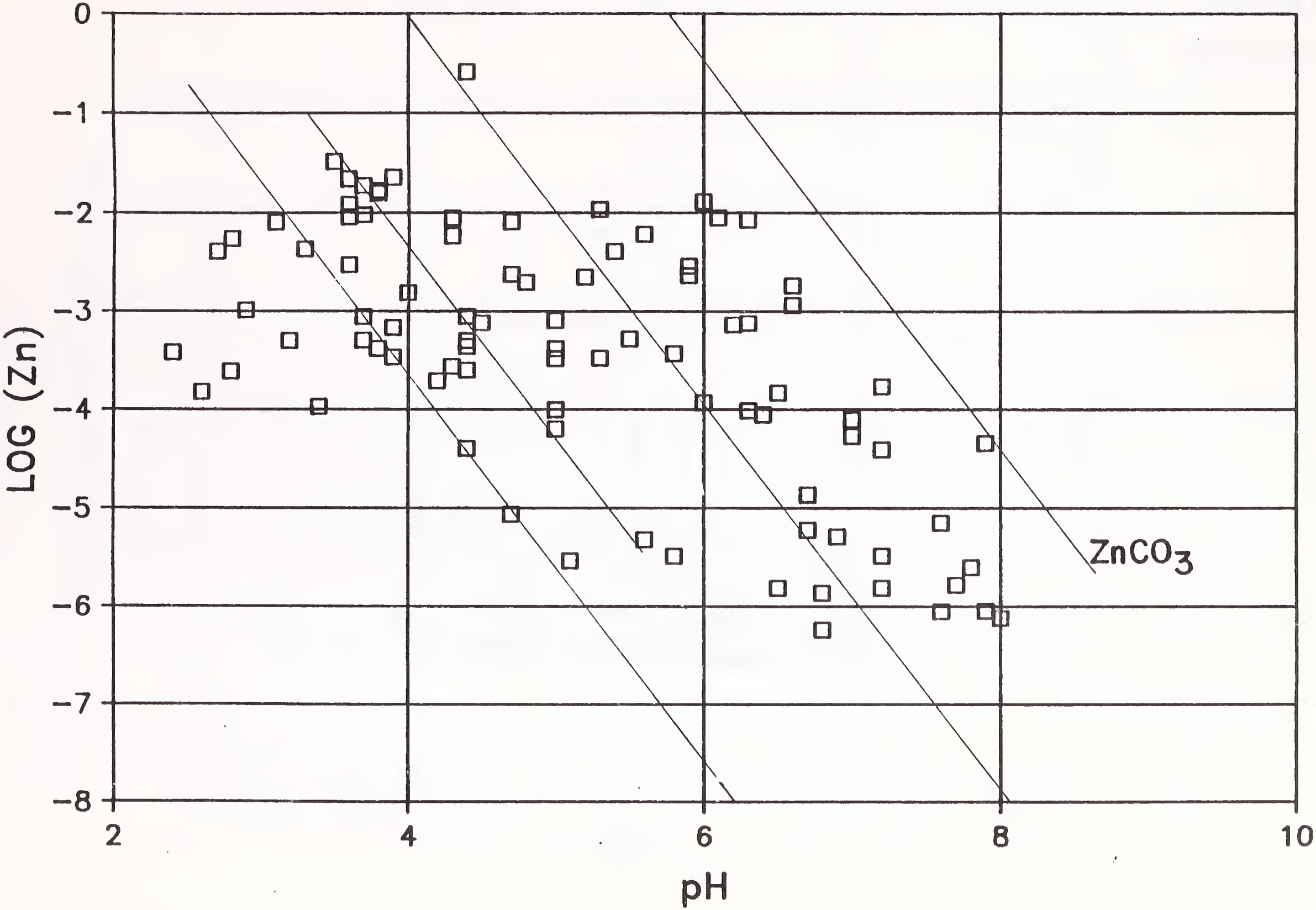


FIGURE 3-34 : ZINC PARTITIONING IN SILVER BOW CREEK RI MATERIAL SAMPLES.

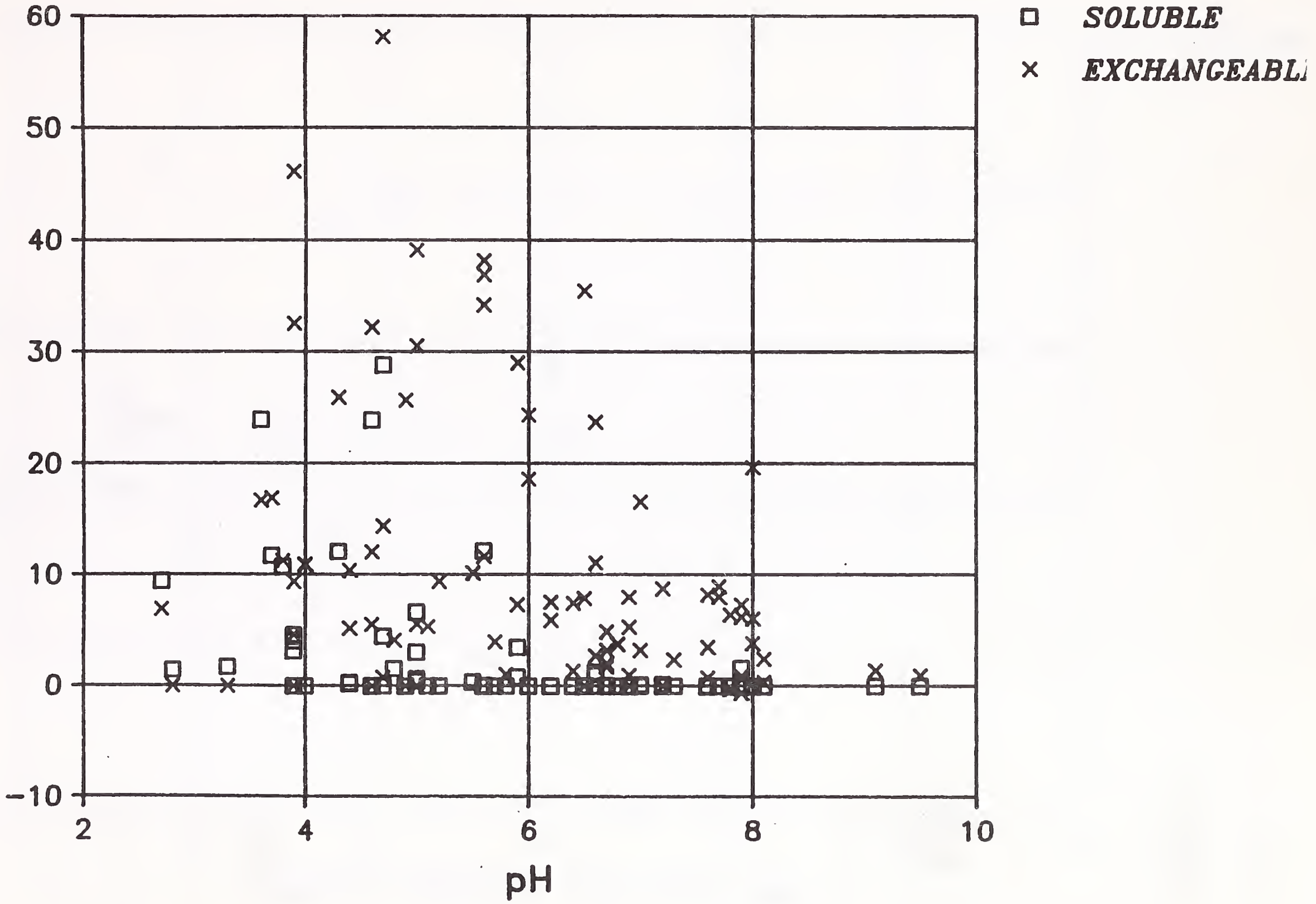
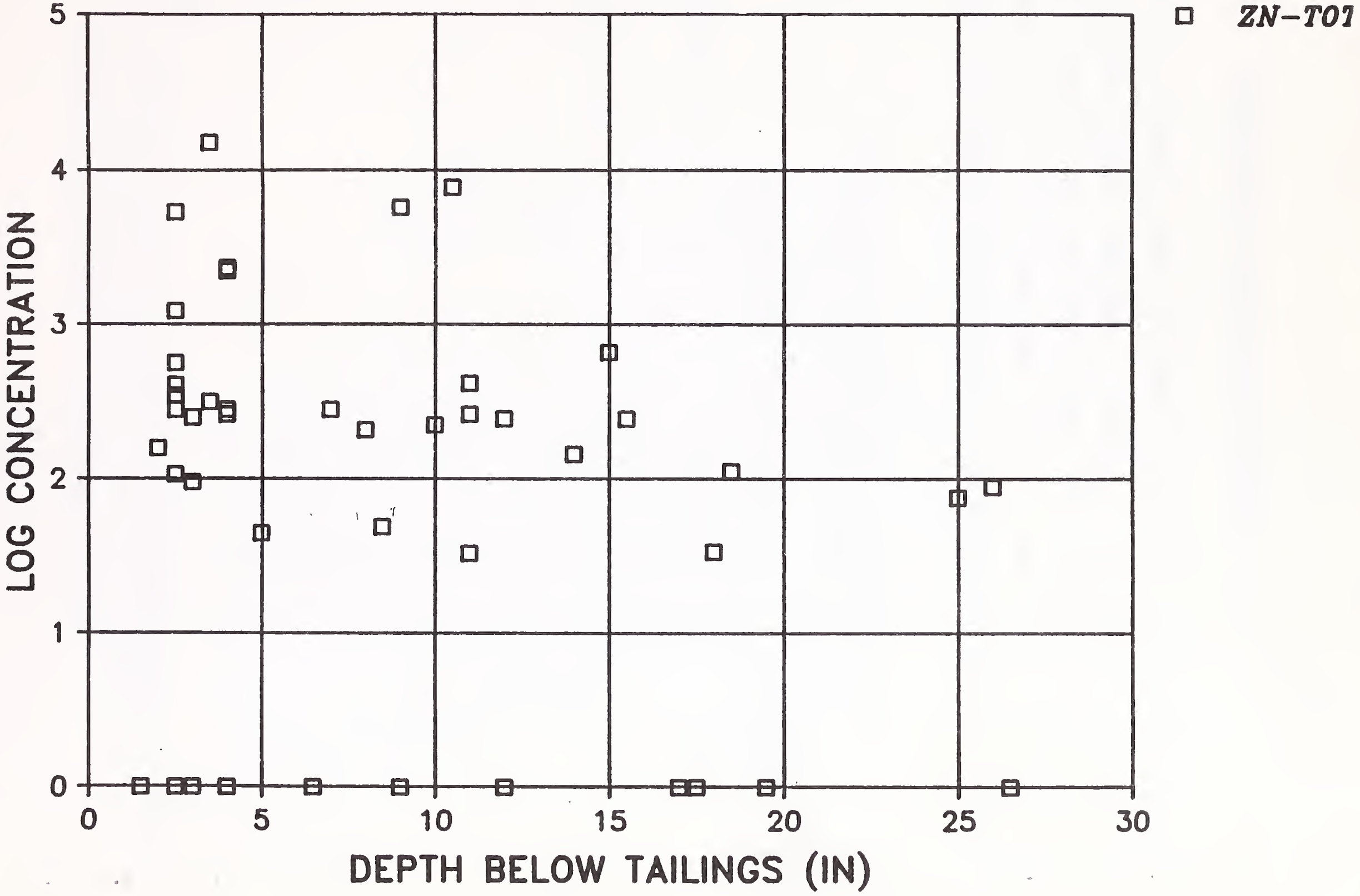


FIGURE 3-35 : PLOT OF TOTAL ZINC VS. DEPTH BELOW TAILINGS ; SILVER BOW CREEK RI.



3.3.2 Ground-Water Flux Through Tailings

No direct studies were performed to quantify mechanisms active in saturated, buried tailings. However, subsurface materials and ground water data collected around the historic Parrot and Butte Reduction Works tailings were used for qualitative descriptions. Table 3-6 compares ground water in buried tailings to materials

TABLE 3-6
COMPARISON OF GROUND WATER IN BURIED TAILING
TO MATERIALS ENCOUNTERED DURING DRILLING

	PARROT TAILINGS		BUTTE REDUCTION WORKS[a]
	Ground Water (GS-10B)[b]	Materials[c]	Ground Water DW-137
Interval (ft)	20-30	20-26	5-10
pH	5.6	4.3	5.4
SC(µmhos/cm)	4480	1343	2040
Eh (mv)	+45	-	+210
Sulfate (mg/l)	1220	-	1640
Cu (mg/l or µg/g)	11.6	63.4	73.4
Zn "	41.5	174	328
Fe "	161	4.1	8.9
As "	.004	-	.014
Pb "	.003	3.7	2.35
Cd "	.325	1.1	2.05

Note:

(a) No material samples collected, but probably similar to Parrot.
(b) Due to construction problems with this well, chemical data should be interpreted cautiously.
(c) Ammonium Acetate @ pH 5.5 extractable metals.

encountered during drilling. Wells listed have completion intervals in or below the tailings. Samples of subsurface material were not collected at well DW-137, but buried tailings here probably have similar levels to those in the Parrot tailings. Ground water is severely degraded by copper, zinc, cadmium, iron, and sulfate at both sites; lead also is elevated in well DW-137. Comparison to material samples showed levels of extractable metals can readily account for observed ground water contaminant levels. These data demonstrate that probably both buried tailings deposits are releasing contaminants to the ground-water system, though the rate of release is unknown.

Mechanisms for release are likely the same as discussed previously, except for some important differences. Eh levels in saturated buried tailings are probably lower than those measured at Ramsay Flats. Stability of sulfide minerals common in tailings is generally greater at these low Eh levels and will affect metal flux to ground water. Generally, Eh levels below 0 mv are required before sulfide minerals are stable at the pH of this system (5.5). Eh measured in ground water is weakly oxidizing (+50 to +200), indicating that oxidation of sulfides is possible thermodynamically. This possibility is also evidence that contaminants can be released to ground water from buried tailings.

Other limiting parameters to contaminant release are due to ground-water flux through the tailings, which is controlled by the local ground-water gradient and the hydraulic conductivity of the tailings.

due to poor sorting and the abundance of fine-grained materials generally found in tailings, conductivities are likely to be moderate to low and this may control contaminant flux to some extent.

3.3.3 Other Mechanisms

The following postulated mechanisms were not tested during this RI. They are primarily hydraulic controls on ground-water movement, and influence the significance of the previous mechanisms.

Discharges from the Weed Concentrator caused ground-water mounding in the upper MSD area. This mounding may cause tailings in the area to become saturated and release contaminants as described in 3.3.2. The mounding may also create a downward component to ground-water movement, driving contaminants to depth. This mechanism is controlled by operational procedures implemented at the concentrator. The downward movement may also represent gravity drainage of the unconsolidated material due to dewatering of the subjacent bedrock.

Geologic structure also may play a role in contaminant movement, especially in the vicinity of Montana Street. A suspected north-south trending fault resulted in an upthrown block present west of this area. This structure may affect ground-water movement in the unconsolidated aquifer, causing deeper water to be forced up, possibly to the surface. Contaminants present in that ground water

would likewise be affected. This physical mechanism may be important with respect to deeper, degraded ground water in the MSD area.

3.4 IMPACTS TO SILVER BOW CREEK

The primary fate of contaminants measured in this study was Silver Bow Creek. The impacts of the two non-point sources, ground water and streamside tailings, are discussed in detail in the Surface Water and Point Source Investigation Report (Appendix A). The major findings are summarized below.

3.4.1 Ground-Water Impacts

Areas of degraded ground-water inflow were identified in Appendix A:

- Along the Metro Storm Drain;
- Along Silver Bow Creek, between Montana Street and the western extent of the Colorado Tailings.

Ground-water degradation of Silver Bow Creek is inferred from data collected at each surface-water sample station. Inflows are best quantified during low-flow periods on the creek, as the inflow has a maximum impact on those occasions and surface-related phenomena are subdued. Impacts to Silver Bow Creek measured during the RI are briefly described below. They are presented in detail in Appendix A.

Most, if not all, of the contaminant loads in the MSD were derived from ground water, although some of the loads may be from sediment re-entrainment. Ground-water inflow to the MSD was a significant source of zinc, cadmium, sulfate, copper, iron, arsenic, and lead to Silver Bow Creek at the confluence with Blacktail Creek, and it degraded water quality at that point.

A significant inflow of contaminated ground water was present between Montana Street and the eastern end of the Colorado Tailings. Large increases in copper, zinc, sulfate, arsenic, and cadmium loads were found in this reach (Appendix A). Ground-water inflow here must be of extremely poor quality to cause these drastic increases in metal loads. The inflow here has many possible origins: the Missoula Gulch alluvial system, the MSD alluvial system forced to the surface by bedrock topography, the Blacktail Creek alluvial sytem, or some combination of these.

Another significant ground-water inflow is present in the Colorado Tailings area. This inflow contributes significant loads of copper, zinc, iron, arsenic, and cadmium to Silver Bow Creek and also must be ground water with high concentrations of contaminants. The inflow may be from beneath the Colorado Tailings or from north of Silver Bow Creek, in the vicinity of the Sewage Treatment Plant.

3.4.2 Streamside Tailings Impacts

Erosion of streamside tailings deposits were not evaluated per se during the RI. Instead, sediment entrainment was quantified, which represents both bank erosion and channel sediment re-entrainment. Distinguishing between the two processes is not possible with existing data.

Surface water data indicate contributions of channel or bank material during higher flows to be significant along Silver Bow Creek from the Colorado Tailings to Silver Bow (SS-07 to SS-10) and from Ramsay Flats to Fairmont Hot Springs (SS-13 to SS-16). In both these reaches, increases in solid-phase metals (copper, zinc, iron, arsenic, and lead) during high flows are significant and consistent. This probably represents previously deposited metals that are remobilized from the stream bottom during higher flows. The lack of extremely high flows during the RI probably prevented significant stream bank tailings erosion from occurring in the study area.

The Surface Water and Point Source Investigation (Appendix A) found both ground water and channel sediments to be major sources of water quality degradation in Silver Bow Creek. Impacts of ground-water inflow were especially severe; impacts of bank entrainment could not be specifically evaluated.

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4.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter reviews the sources, transport, and fate of contaminants measured during the Silver Bow Creek (SBC) Remedial Investigation (RI). The severity and extent of contamination also is presented. Conclusions are based primarily on data collected during this RI (December 1984-January 1986) and not on historic data. The chapter ends with recommendations for additional data collection.

Conclusions for this RI are based on data collected during a period of drier-than-average weather, as shown in precipitation and snowpack records and flows in Silver Bow Creek. The drier weather created an opportunity to study ground-water inflows to Silver Bow Creek.

4.1 SEVERITY AND EXTENT OF CONTAMINATION

This RI found definite evidence of ground-water contamination in the Silver Bow Creek study area. This contamination indicates a severely degraded resource and may pose hazards to human health, as well as to aquatic life and the environment. Limitations on the present and future use of ground-water resources is an additional problem.

Federal drinking water standards were exceeded for most parameters at several wells sampled in the RI study area (Table 4-1). Concentration exceedences were measured for arsenic, cadmium, copper,

TABLE 4-1
EXCEEDENCES OF USEPA PRIMARY AND SECONDARY DRINKING WATER CRITERIA IN GROUND WATER SAMPLED DURING THE SBC RI[a]

		Primary Criteria[b]			Secondary Criteria[b]			
Sample Site	# of Samples	As	Cd	Pb	Cu	Zn	Fe	SO_4
DW-101	2		2		2	2	2	2
DW-102	3		3			3	3	3
DW-103	2						1	
DW-105	4		4			4	4	4
DW-106	2		1				2	
DW-107	3						3	3
DW-108	1		1			1		1
DW-109	3	2	1			1	3	2
DW-110	3	1				3	3	3
DW-112	4		1				4	4
DW-114	3		1				2	3
DW-115	3							2
DW-116	4		4				4	4
DW-117	1							1
DW-118	3	1					3	3
DW-119	4	2					4	4
DW-121	4							1
DW-123	1							1
DW-124	2							2
DW-125	1							1
DW-130	4							4
DW-131	3						1	3
DW-132	1					1		1
DW-133	2							2
DW-134	2					2		2
DW-136	1		1	1	1	1	1	1
DW-137	2		2	2	2	2	2	2
DW-202	2							2
DW-206	2		1					
DW-207	3							3
DW-311	1							1
DW-314	1							1
DW 318	2							2
DW-336	1						1	
DW-337	1						1	
DW-504	1							1
Standard (mg/L)		0.05	0.01	0.05	1.0	5.0	0.3	250

TABLE 4-1
EXCEEDENCES OF USEPA PRIMARY AND SECONDARY DRINKING
WATER CRITERIA IN GROUND WATER SAMPLED DURING THE SBC RI[a] (Cont.)

		Primary Criteria[b]			Secondary Criteria[b]			
Sample Site	# of Samples	As	Cd	Pb	Cu	Zn	Fe	SO_4
GS-02	2						2	
GS-05	3						3	
GS-06	3		1				3	3
GS-07	2		2		2	2	1	2
GS-08	2		1					2
GS-09	2		2		2			2
GS-10A	2		2		2			2
GS-10B	2		2	1	2			2
GS-11	2		2		2	2	2	2
GS-13A	2		2	2		2	2	2
GS-13B	2		1				2	1
GS-14	3							3
TS-01	4							3
TS-10	7		1				2	3
TS-11	8	8	1	1				2
TS-14	3		3	1		2	3	3
TS-15	3		2				2	1
TS-16	2		2	2	2	2	1	2
Standard (mg/L)		0.05	0.01	0.05	1.0	5.0	0.3	250

Notes:

(a) Based on Dissolved Concentrations
(b) USEPA 1976

iron, lead, zinc, and sulfate. The majority of the drinking water exceedences for individual metals and sulfate occurred in monitoring wells in the MSD area and upper Silver Bow Creek. Domestic wells that exhibited exceedences of Federal drinking water standards are identified in Table 4-2. Most of these exceedences were for secondary standards; an exception was cadmium, which exceeded primary standards at one domestic well. Few exceedences of metal parameters were measured in any domestic wells sampled, although several wells approached the standard for arsenic.

TABLE 4-2

SUMMARY OF DOMESTIC WELLS[a] EXHIBITING FEDERAL DRINKING WATER STANDARD EXCEEDENCES[b]

Sulfate	Cadmium	Iron	Arsenic	Zinc
DW-131	DW-206	DW-131	DW-230[c]	DW-132
DW-132		DW-336		
DW-202		DW-337		
DW-207				
DW-311				
DW-314				
DW-318				
DW-504				

Notes:

(a) Well locations shown on Maps 1-2 through 1-5 (Over Size)

(b) USEPA 1976

(c) Exceedence measured was for total fraction; corresponding dissolved fraction was less than standard of 0.05 mg/L.

The extent of ground-water contamination in the RI study area was identified in general; exact boundaries of degraded ground water were not discerned. Ground-water contamination is most prominent in the MSD area and upper Silver Bow Creek; it is associated with the Silver Bow Creek alluvium and underlying unconsolidated material aquifers. The shallow portions of the aquifers are typically most degraded; ground-water quality generally improves with depth.

Ground water underlying streamside tailings deposits in areas downstream from Rocker are generally not contaminated. Some samples indicate the upper portion of the alluvial aquifer underlying the Ramsay Flats tailings deposit is degraded slightly when compared with deeper portions of the aquifer. Tailings deposits on the Clark Fork River floodplain may degrade shallow ground water locally, but impacts were not documented during the RI. Floodplain tailings deposits occur at least as far downstream as Gold Creek. Because precipitation was below normal, the impact that overlying tailings exert on shallow ground-water quality may not have been completely characterized during the RI.

Areas of historically irrigated land have been extensively damaged on low terraces bordering the Clark Fork River (see Agriculture Report, Appendix D, Part 3). Most of these lands will support at least sparse vegetation and are used for agricultural production. These lands have the potential for accumulation of metals in the food chain, and may be a source of fugitive dust in the Deer Lodge Valley. The extent of contamination of irrigated areas west of the

Clark Fork River from Warm Springs to Deer Lodge is uncertain due to the variety of water sources used for surface irrigation.

4.2 CONTAMINANT SOURCES

Several potential sources of ground-water contamination were evaluated during the RI: Upper MSD (Parrot tailings), Weed concentrator, STP vicinity (Butte Reduction Works), Colorado tailings, Anaconda Pole Treatment Facility, Ramsay Flats, and fluvial tailings along Silver Bow Creek and the Clark Fork River. Table 4-3 summarizes the major findings concerning each of these potential sources evaluated during the RI.

The Surface-Water and Point Source Investigation (Appendix A) identified significant contaminated ground-water inflows in the MSD (SS-02 to SS-03) and between Montana Street and the western end of the Colorado Tailings (SS-05 to SS-07). Sources of contaminants to ground water in both the MSD and upper Silver Bow Creek areas should be considered high priority problems: buried tailings in the upper MSD (Parrot), those in the STP vicinity (Butte Reduction Works), the Colorado Tailings, and possibly the Anaconda Pole Treatment Facility.

4.3 CONTAMINANT TRANSPORT

Several mechanisms may be responsible for mobilizing contaminants into surface and ground waters in the RI study area: (1) direct

TABLE 4-3

SUMMARY OF POTENTIAL GROUND-WATER CONTAMINATION SOURCES
FOUND DURING THE SBC RI

Potential Source	Type	RI Findings
Upper MSD (Parrot)	Buried Tailings	Subsurface material has extreme levels of metals. Ground water in, beneath, and downgradient from tailings is degraded.
Weed Concentrator	Discharge or Process Waters	Not evaluated, but a potential source, and may have amplified problems from buried tailings in MSD area.
STP Vicinity (Butte Reduction Works)	Buried Tailings	No appropriate tailings analysis. Ground water beneath and downgradient is severely degraded.
Colorado Tailings	Surface Tailings	Tailings have elevated metals and contaminated soils and ground water beneath (MBMG data). Metals concentrations in ground water increase to the northwest.
Anaconda Pole Treatment	Surface Soil Contamination	Surface soils have extreme levels of arsenic. Ground water not characterized.
Ramsay Flats	Surface Tailings	Tailings contain up to 60 times background metals. Surface efforescence contains extreme concentrations of metals (up to 15%). Underlying shallow ground water is degraded but, due to low gradients and transmissivity, does not move away from the site significantly.
Fluvial Tailings Along SBC and CFR	Surface Tailings	Tailings have elevated metals. Ground water may be locally affected but no significant ground-water contamination was found in the areas examined.

infiltration through tailings into underlying ground water; (2) ground-water flux through tailings deposits; (3) capillary action driving metallic salts to the surface and entrainment by surface runoff; and (4) direct erosion and entrainment of streamside tailings. Other, less prominent, mechanisms include bank storage releases, artificial ground-water mounding, and geologic structure.

Infiltration studies performed on exposed tailings showed total, soluble, and acid extractable metals were greatly elevated. Partitioning of copper, zinc, cadmium, manganese, and occasionally iron into the soluble fraction at the low pH observed in the tailings indicates a significant potential for movement into ground water and surface water. Metal distribution in natural soils below the tailings indicates that these metals and arsenic have moved out of tailings, from five inches (lead) to more than 20 inches (cadmium, arsenic). The order of apparent decreasing mobility is arsenic > cadmium > zinc > copper > lead. Iron and manganese flux is uncertain due to their high background levels and limited enrichment; however, manganese appears similar to zinc in mobility.

Iron and manganese oxides have a tendency to adsorb or co-precipitate copper, arsenic, zinc and, to a limited extent, cadmium from solution. If the pH + pe in the buried natural soils is above 12 to 15, these oxides would likely attenuate copper, zinc, and arsenic movement. However, no evidence indicates metal accumulation at the base of the tailings. Arsenic mobility is further affected by its valence state, which is determined by the redox potential. If the

pH + pe is 10 or lower in some buried soils, metal mobility would be enhanced. As a result, metals could be expected to move into ground water if significant recharge occurs.

Analyses of water flux in the vadose zone and pore water chemistry during the investigation indicate that only a limited amount of water movement occurred from tailings into the ground water. The period of study was drier than normal and preliminary computer modeling indicates that water flux would be substantial during more normal to above normal precipitation periods.

Ground-water flux through buried tailings was not studied directly, but data collected around subsurface tailings was examined. The data demonstrate that tailings were releasing contaminants to ground water. Two controls on contaminant flux were postulated: lower Eh levels increasing sulfide stabilities, and low transmissivity within tailings deposits.

Accumulation of metal-rich, complex mixed-sulfate salts and hydrated oxide salts at tailings surfaces suggests a potential for entrainment of contaminants via surface runoff from areas of bare deposits. Entrainment of streamside tailings materials may occur during bankfull or flood stage events (see Appendix A, Surface Water and Point Source report).

The release of bank storage water during declining creek stage may also contribute to metal loading. Due to the lack of water use by

plants and the high permeability of the sandy tailings deposits, recharge of the alluvial aquifer from overlying tailings adjacent to the creek may occur. This water may be highly contaminated with metals if the vadose zone has reduced pH (<4.5 to 5.0) or low Eh (<50 to -50 mv) conditions.

Discharges from the Weed Concentrator or underlying dewatered bedrock may create a downward component to ground-water movement in the upper MSD area, driving contaminants to depth. A postulated fault in the vicinity of Montana Street may be causing contaminated ground water to surface in the area.

4.4 IMPACTS TO SILVER BOW CREEK

The Surface Water and Point Source Investigation (Appendix A) identified ground-water inflows as a significant source of metals loading to Silver Bow Creek.

Ground-water and sediment contributions to Silver Bow Creek are presented and analyzed in Appendix A. The ground-water inflow to the MSD causes the MSD to be a significant source of zinc, cadmium and sulfate to Silver Bow Creek. Ground water entering the creek between Montana Street and the Colorado Tailings is a major source of copper, zinc, arsenic, cadmium, and sulfate to Silver Bow Creek. Previously deposited channel or bank sediments appear to be mobilized during higher flows in two areas, though flows were probably not high enough to cause significant streambank tailings erosion

during this RI. Remobilized sediments were a source of iron, arsenic, and lead to Silver Bow Creek during the RI (Appendix A).

It is difficult to delineate specific areas (e.g., Butte Reduction Works or Colorado Tailings) as being responsible for a quantifiable percentage of the metals load in Silver Bow Creek. A portion of ground-water contamination in one area moves through the subsurface and discharges to Silver Bow Creek in another, downgradient area. Because of this movement, absolute quantification of the ground-water impact in a specific area on metals loading in Silver Bow Creek is not likely to be accurate.

4.5 RECOMMENDATIONS

This section recommends additional data collection that may be necessary for the completion of the feasibility study on Silver Bow Creek. Justification for each of the data needs is provided also. Additional data is needed are three areas:

(1) Further delineation of the source and extent of ground-water contamination in the upper MSD area and in the vicinity of the Butte Reduction Works tailings impoundments. Although RI data identified these areas as sources of ground-water contamination, data were insufficient to delineate the extent of affected ground water or to ascertain geochemical mechanisms causing release of contaminants. Further characterization is required

for buried tailings in areas contributing most to the degradation of water quality in the MSD and upper Silver Bow Creek (Parrot and Butte Reduction Works tailings).

(2) An analysis of historic water quality data (if available) from process ponds located on the Weed Concentrator complex and associated discharges to the MSD from the facility should be completed to ascertain the potential of this site as a past or future source of ground-water contamination. Current ground-water quality conditions in the area may be a result of this historic contaminant source, which was not evaluated during the RI because it was not part of the defined study area.

(3) Continued characterization of the vadose zone is necessary to further calibrate geochemical and water budget models developed for the RI study area. These data are important because although major ground-water contamination at Ramsay Flats was not suggested by the study, soil chemistry and suction lysimeter results indicate that metal flux to ground water is likely if significant direct recharge occurs through the tailings. Therefore, studies performed during a year of average or above-average precipitation would more accurately characterize impacts of surface tailings.

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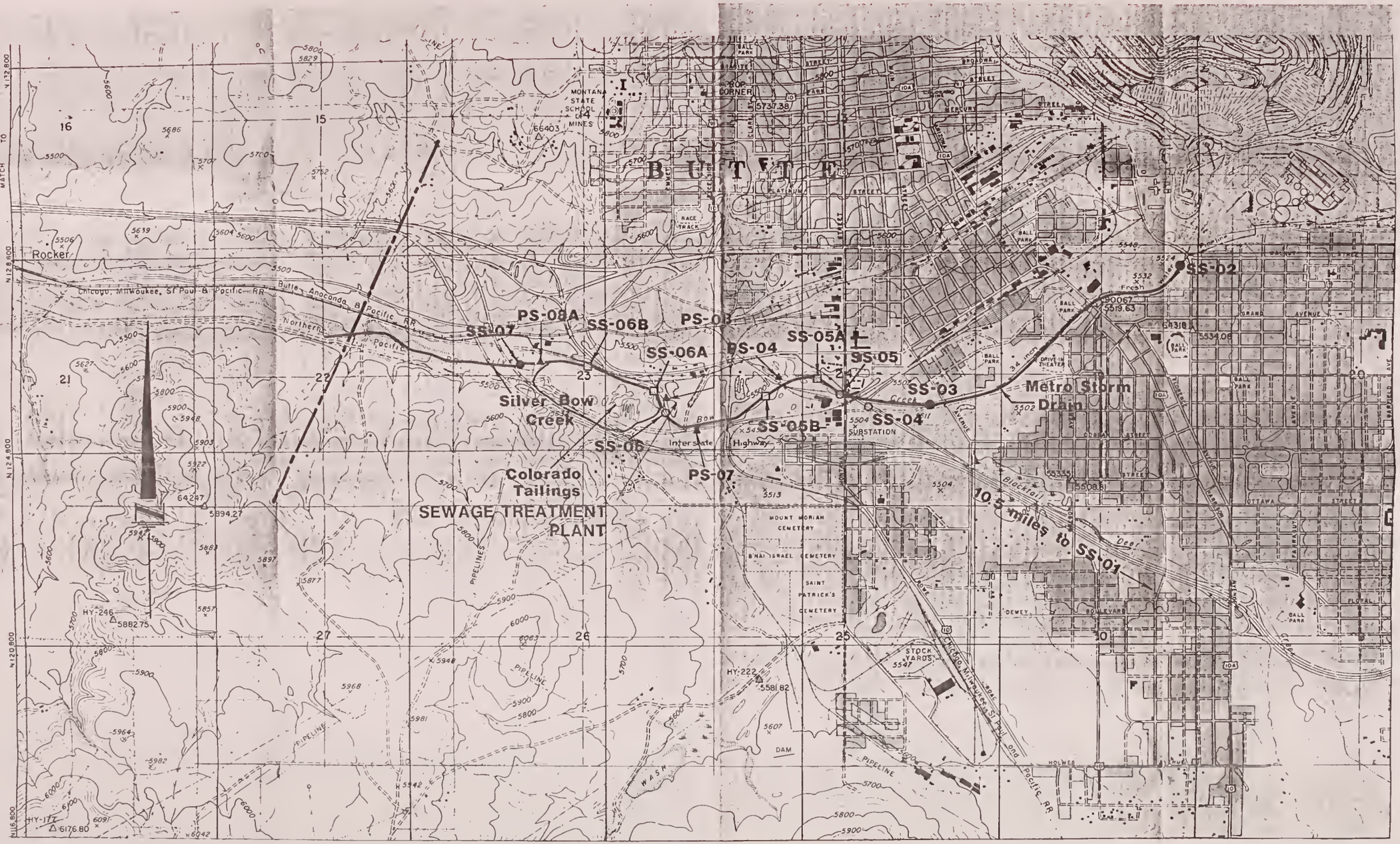
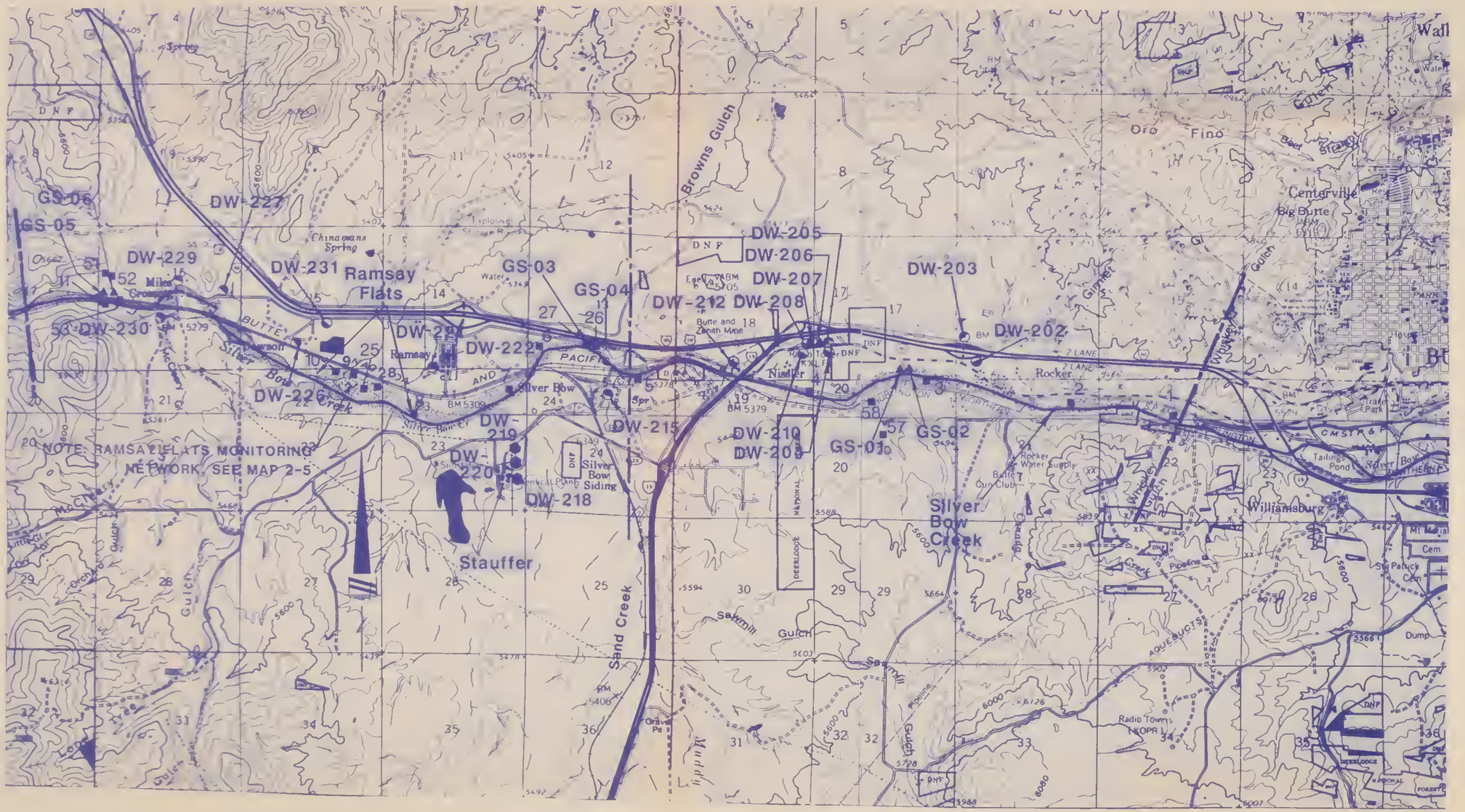


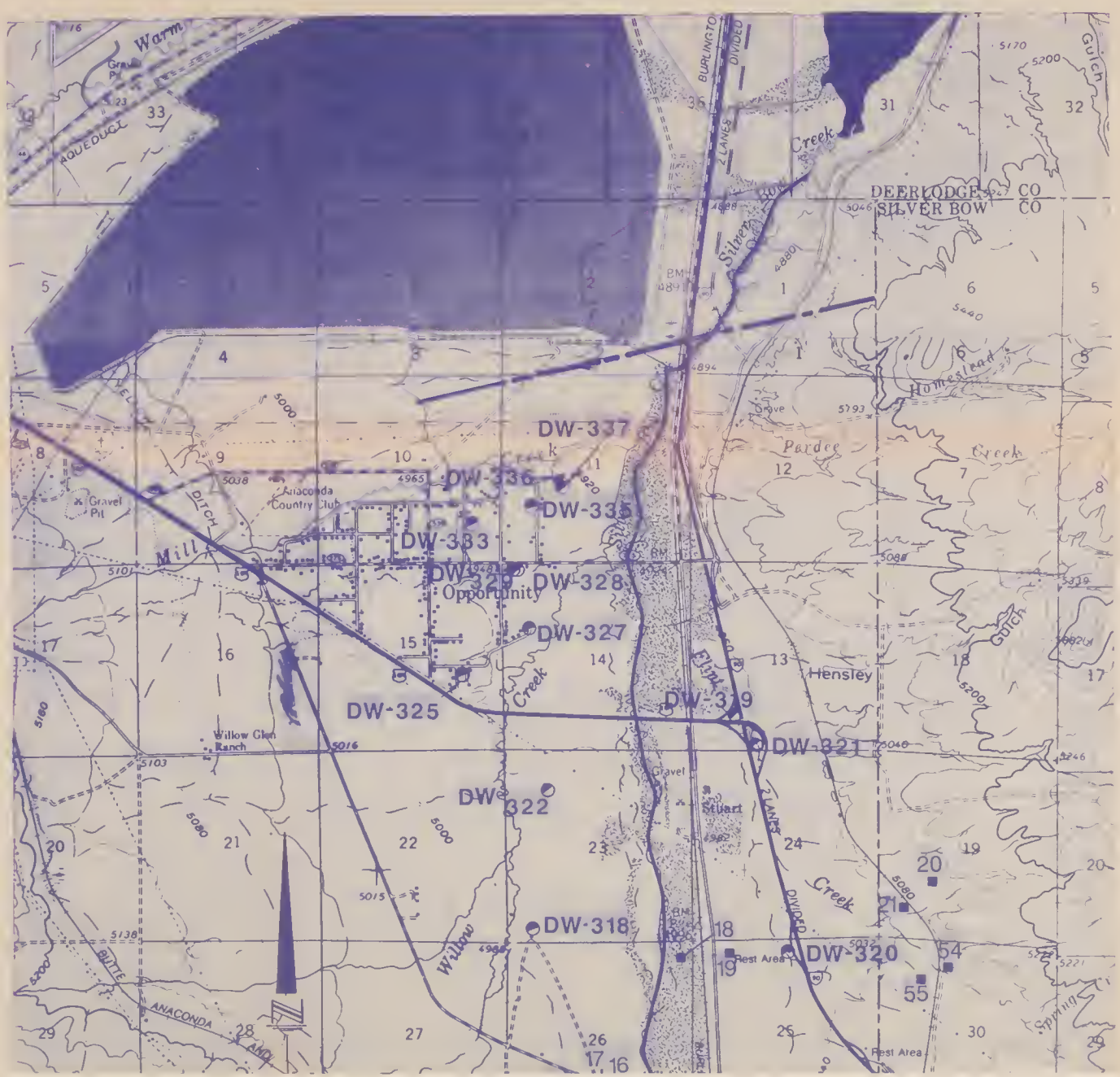
LEGEND

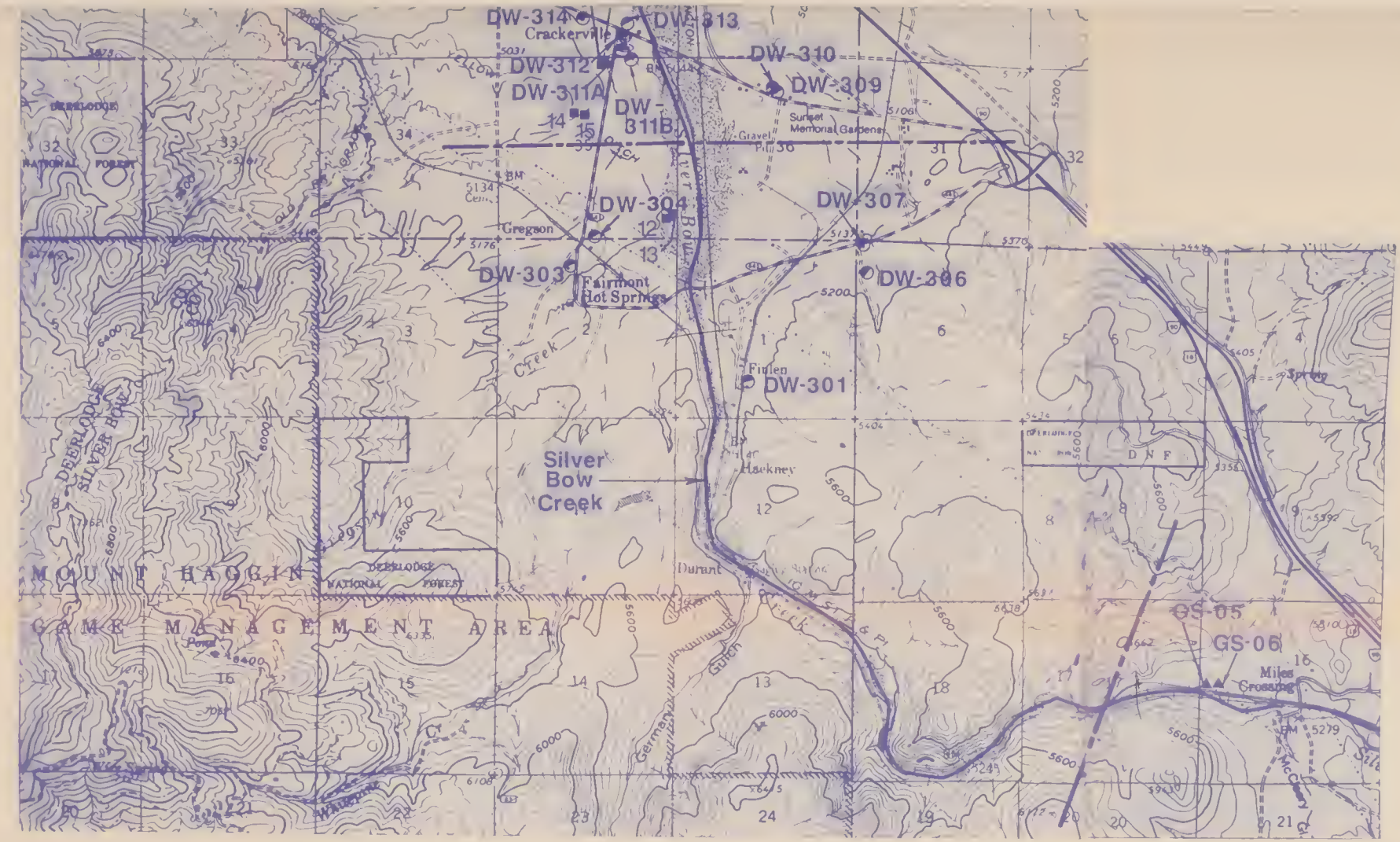
- ○ SURFACE WATER SAMPLE SITE
- ● PERMANENT GAGE SITE AND SURFACE WATER SAMPLE SITE
- ▲ POINT SOURCE SAMPLE SITE
- □ SEEPAGE SURFACE WATER SAMPLE SITE

0 1000' 2000'

SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-2
BUTTE TO WHISKEY GULCH


GS-06
GS-05
DW-227
DW-229
DW-231
Ramsay Flats
GS-03
GS-04
DW-230
DW-228
DW-222
DW-226
DW-219
DW-220
DW-218
DW-215
DW-205
DW-206
DW-207
DW-212
DW-208
DW-210
DW-209
DW-203
DW-202
GS-01
GS-02
NOTE: RAMSAY FLATS MONITORING NETWORK, SEE MAP 2-5
Browns Gulch
Stauffer
Sand Creek
Silver Bow Creek
Centerville
Big Butte
Oro Fino
Rocker
Nissler
Williamsburg
Miles Crossing
Ramsay
Silver Bow
Butte and Zenith Mine
Radio Towers (KOPR)
Tailings Pond
Water Supply
Gun Club
Dump
Cem
Pipeline
Aqueducts
Gravel Pit
Concrete Plant
Silver Bow Siding
Chinaman Spring
Explosive Storage
Sawmill Gulch
Orchard Gulch
Lodge Gulch
Butte Silver Bow Creek
Pacific and Northern
Great Northern
Milwaukee
Northern Pacific
Deerlodge National Forest
Interlodge National Forest
LEGEND
SILVER BOW CREEK REMEDIAL INVESTIGATION MAP 1-3 WHISKEY GULCH TO MILES CROSSING


DW-337
DW-336
DW-335
DW-333
DW-329
DW-328
DW-327
DW-325
DW-322
DW-319
DW-321
DW-318
DW-320
DEER LODGE CO
SILVER BOW CO
Anaconda Country Club
Gravel Pit
Opportunity
Hensley
Stuart
Willow Glen Ranch
Rest Area
Rest Area
Warm
AQUEDUCT
Mill
DITCH
Silver
Creek
Pardee
Creek
Homestead
Gulch
Gulch
Willow
Creek
Flint
Creek
Spring
Creek
BURLINGTON
DIVIDED
2 LANES
DIVIDED
2 LANES
BUTTE
ANACONDA
HWY



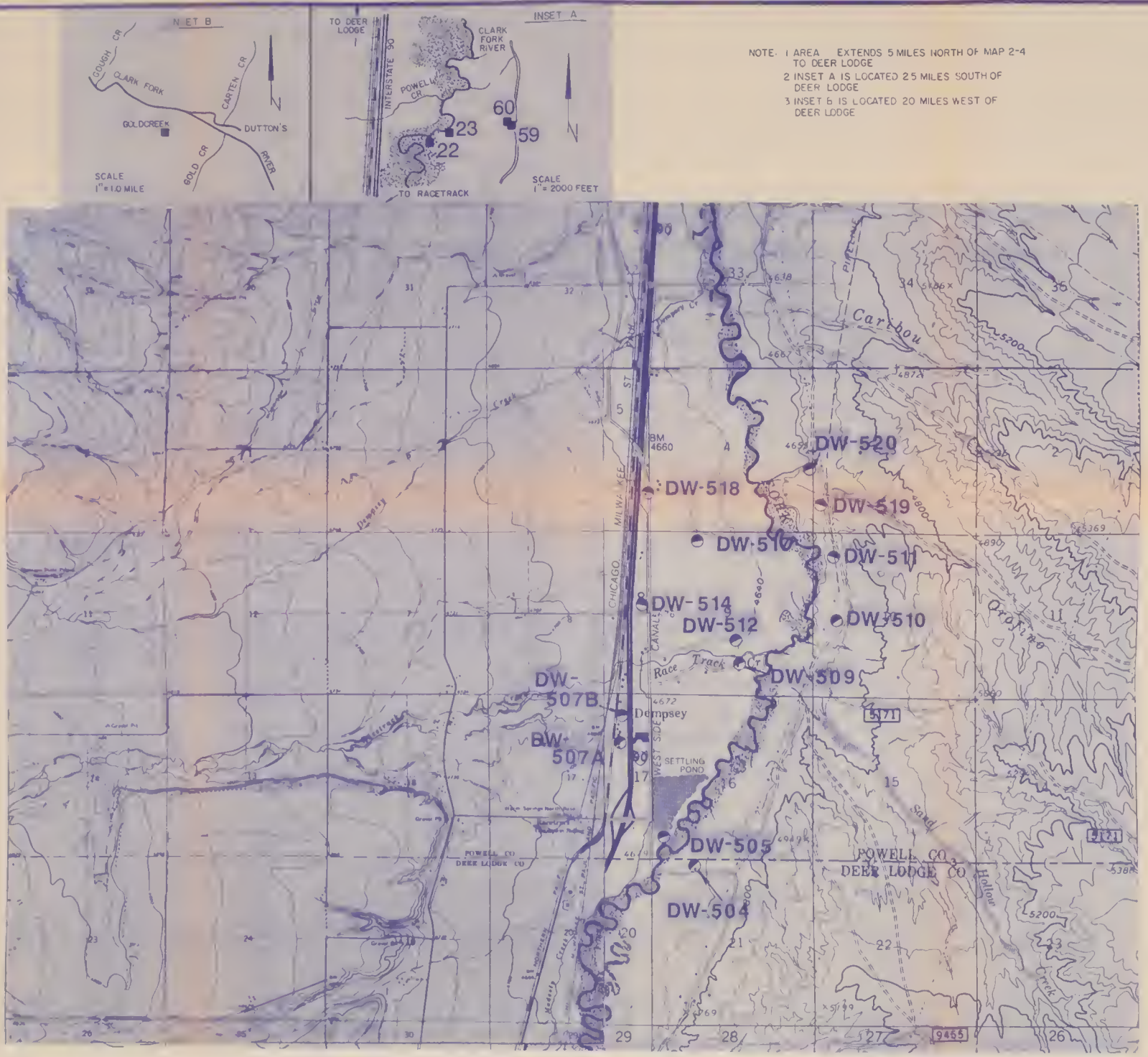
LEGEND

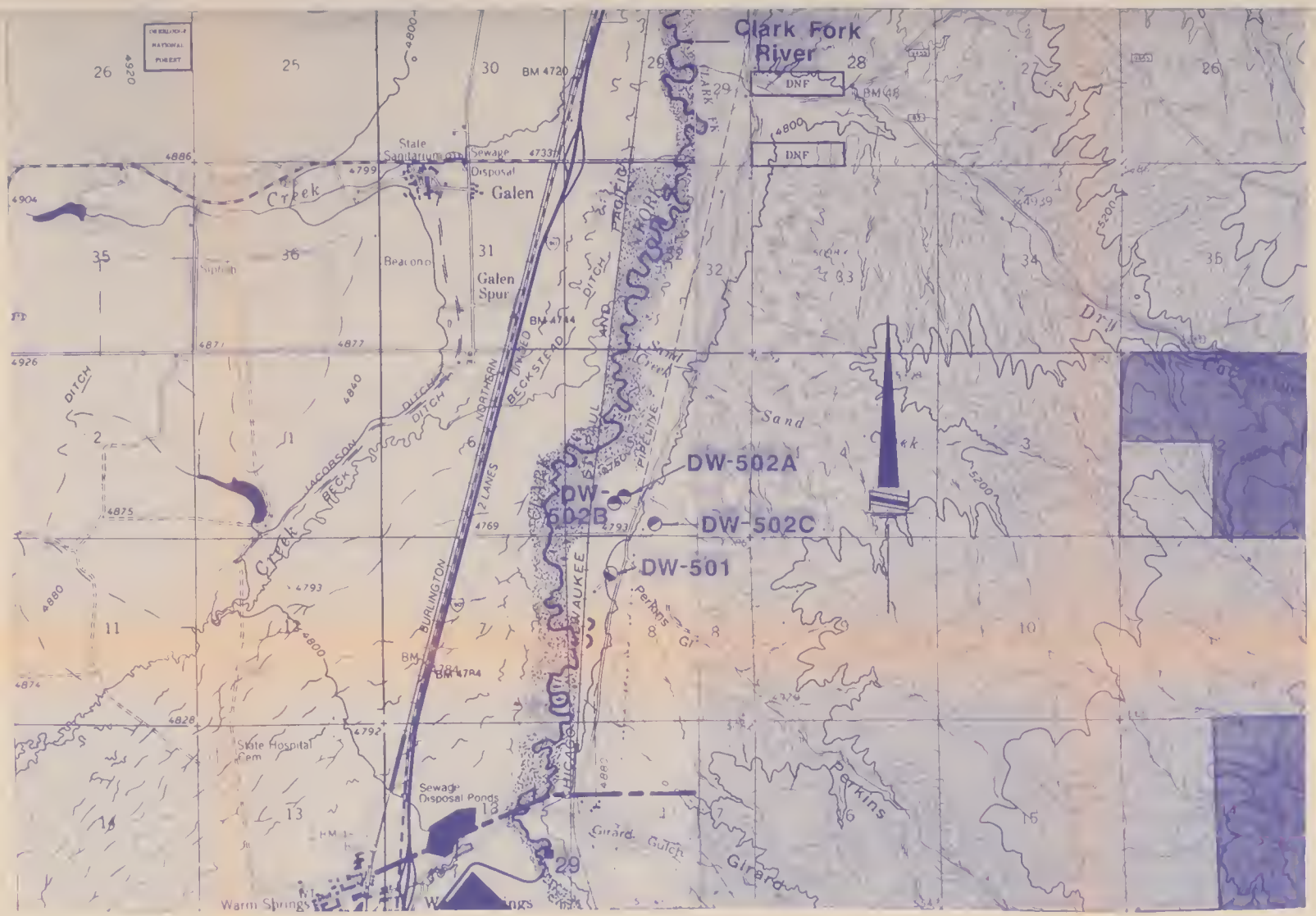
SILVER BOW CREEK

REMEDIAL INVESTIGATION

MAP 1-4

MILES CROSSING TO WARM SPRINGS PONDS


INSET B
GOUGH CR
CLARK FORK
CARTEN CR
GOLDCREEK
DUTTON'S
GOLD CR
RIVER
SCALE
1" = 1.0 MILE
INSET A
TO DEER LODGE
INTERSTATE 90
CLARK FORK RIVER
POWELL CR
23
22
60
59
TO RACETRACK
SCALE
1" = 2000 FEET
NOTE: 1 AREA EXTENDS 5 MILES NORTH OF MAP 2-4 TO DEER LODGE
2 INSET A IS LOCATED 2.5 MILES SOUTH OF DEER LODGE
3 INSET B IS LOCATED 20 MILES WEST OF DEER LODGE
DW-520
DW-518
DW-519
DW-516
DW-511
DW-514
DW-512
DW-510
DW-509
DW-507B
DW-507A
DW-505
DW-504
Carbou
Dempsey
Race Track Cr
Prairie
Sand
Hollow
CHICAGO MILWAUKEE ST PAUL
WEST SIDE CANAL
SETTLING POND
POWELL CO
DEER LODGE CO
BM 4660
4672
5171
9455



LEGEND

SILVER BOW CREEK
REMEDIAL INVESTIGATION
MAP 1-5
UPPER CLARK FORK RIVER